AGROECOSYSTEMS FOR COMMUNITIES AND CONSERVATION:

LINKING BIRD CONSERVATION AND SUSTAINABLE LIVELIHOODS IN THE HIGHLANDS OF GUATEMALA

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by

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ABSTRACT

As the world's natural habitats continue to be converted for human use, integrating biodiversity conservation within the activities that support sustainable development is vital, yet increasingly challenging in regions where high levels of poverty and biodiversity converge. Conservation of tropical forests, therefore, depends upon effectively managing agroecosystems to support rural livelihoods, food security, and wildlife. A land use approach that integrates diverse agroecosystems with natural habitats is one strategy to achieve multiple human and environmental targets, but its success depends upon identification of agricultural practices that are biodiversity-friendly. Our research asked three main questions: 1) In what ways can tropical agroecosystems support bird conservation? 2) Which agricultural practices best support sustainable livelihoods in rural communities? 3) Which agroecosystem characteristics most align with the shared goals of promoting healthy human communities and conserving biodiversity? From June 2014 to February 2015, we used a mixed-methods approach to address our questions within three remote villages in the Central Highlands in the Department of Alta Verapaz, Guatemala, an area globally recognized for its biocultural diversity. We measured occupancy of 15 focal bird species, vegetation characteristics, and landscape context at 142 points located in six agroecosystems types (i.e. monoculture, polyculture, semi-shade coffee, pine plantation, secondary forest, and primary cloud forest). We also surveyed 42 farmer households to assess crop diversity, dietary diversity, agrochemical use practices and income generated from crop sales.

Our work shows that conservation and sustainable livelihoods were best supported by diverse agroecosystems that retained cloud forest remnants within the matrix. Structural and floristic diversity of agroecosystems were positively associated with focal bird species as well as diversified diets and on-farm incomes for farmers. For birds of conservation concern, the value of agroecosystems can be improved by retaining >20% canopy cover on farms and >60% in forest

habitats, maintaining 150-550 trees/ha, protecting epiphytes, and managing landscapes for 25-40% forest within the matrix. Efforts to plant trees, especially fruit trees, and culturally significant heirloom crops, are thus likely to restore or enhance avian habitat within the agricultural matrix.

Diverse agroecosystems with remnant forests also supported farmers and their families within rural Q'eqchi' communities. In particular, crop diversity was positively associated to dietary diversity, an indicator of nutritional status, such that one additional food group was consumed within a household for each 5 crops added. On-farm income sources also diversified with crop variety, given that the average household sold approximately one-third of their total crop diversity. Specific types of heirloom and fruit crops (e.g., roctixl, macuy, ch'onte', guisquil, taro, chilacayote, pacaya palm, peach, plum, avocado, passionfruit) were especially likely to result in positive social and environmental outcomes. In contrast, other crops (e.g., export broccoli, cash crops) were more lucrative, but required expensive and potentially harmful agrochemicals. Collectively, these findings were used to inform management through an agroecological enrichment project with local partners that reintroduced heirloom crops and planted fruit trees in 18 remote communities, and engaged over 15 stakeholder groups in participatory discussions about conservation and development within the greater Highlands of Alta Verapaz, Guatemala. Overall, identifying and advocating for biodiversity-friendly agroecosystems is likely to contribute to bird conservation and sustainable livelihoods in the Highlands of Guatemala. More information about this project can be found at www.conservationforcommunities.weebly.com.

BIOGRAPHICAL SKETCH

Gemara grew up humbly in Arvada, Colorado with her brother, Chase, mother, Tina, and with the dream of one day making the world a better place for animals. At age 6, she was encouraged by her mother to send a letter to President Bill Clinton about this worldview, and within a month she received a signed letter of support back, and a photo of Socks, the White House cat. With early motivation to "dream big," at age 7 she organized for prairie dog conservation, and at 10 won 1st place at the elementary science fair for her research on turgor pressure in chicken eggs, and to this day she is still not quite sure what that is. Gem did not realize at a young age that her love for animals and the outdoors would ultimately take her on a lifetime adventure around the world and on many career paths studying wildlife conservation. It wasn't until she reached 18 that her dream seemed closer. This was when she received the prestigious Gates Millennium Scholarship, a 10-year full-ride scholarship for underprivileged students in higher education. That very day, she quit her job as a drive-thru cashier, and began planning.

The next four years at Colorado State University, in Fort Collins, Colorado, were some of the best years of her life. As a first-generation college student, Gem graduated Magna Cum Laude with a major in Zoology and minors in Ethnic Studies and Conservation Biology. Early on, she became involved with the Department of Natural Resources where she worked as an environmental educator for almost four years. Gem found a passion for teaching, and designing programs that would connect low-income and Hispanic families to nature in Fort Collins. While juggling a full class load, she took a second job as a zookeeper at the Denver Zoo, where she would train Asian Elephants, Black Rhinos, marine mammals, and care for hundreds of bird species. Then, her Junior year, she worked with a Cornell Lab of Ornithology Alumna on an honors thesis project, and as soon as she sank her boots into the tropical forests of Costa Rica, the game had changed. Torn between a love for domestic and wild animals, as well as social justice for marginalized communities in the US, she

wasn't sure which path to take. During a year of "creative rest," post-graduation, she thought deeply (and briefly) about her future until she soon became distracted by her passion for music and joined a rock band as a singer and saxophone player where she would meet her current love and rock-star, Travis. The same year, she balanced her creative lifestyle with field jobs working for the US Forest Service, and Colorado Parks and Wildlife, where she studied the effects of oil development on the Greater Sage-grouse and monitored sensitive forest species in the mountains of Colorado. Field seasons came to a close, and soon enough, Gem found out she had been accepted as a graduate student at Cornell – an Ivy League – which was both exciting and terrifying. The summer prior, Gem ended up in the cloud forests of Honduras where she organized a Bilingual environmental education program for girls, and took a wonderful cross-country trip to New York with Travis.

Pleasantly surprised, the next two and a half years at Cornell University would perfectly blend her passions for wildlife conservation and social justice. Guatemala was an ideal location to do so. There, she would study bird conservation in diverse Mayan agroecosystems, and discover a passion for food sovereignty and agroecology along the way. When she wasn't in the field, Ithaca was a cute and cold town, filled with incredible people, wine, cheese, and a little kitten she'd eventually adopt and name after a Guatemalan bird. She'd become involved with, and start her own initiatives to support underrepresented students at Cornell, and eventually meet Bill Gates in person to thank him for doing the same. As she looks back on her triple life as a Master's student (in New York, Colorado, and Guatemala), she is humbled by how challenging it has been and the achievements she has made. While she did not come out unscathed, her experience at Cornell and in Guatemala was a "beautiful disaster," that left a profound impact on her life which will take years to fully reflect upon. Looking forward to another period of "creative rest," she hopes songwriting with Travis will help her do so.

DEDICATION

To Renee and my mom, Tina

for giving me a deep love for animals

which will always remain a theme in my life.

"Dream big!"

Gem and Renee, ages 10 and 1.

AKNOWLEDGEMENTS

First and foremost, I'd like to thank my committee for their invaluable advice over the past two years. My advisor, Amanda, taught me to become a better writer and researcher, and challenged me beyond what I even thought I was capable of achieving, and for that I am so grateful. Miguel provided important guidance within a field I was relatively new to, and Eduardo was my cheerleader from the beginning, and the first to encourage me to conduct my research in Guatemala. I am so glad I listened. There are two honorary committee members to note including Wesley Hochachka who provided his time, wit, and expertise in statistics, and Viviana Ruiz-Gutierrez for being my big sister back in Colorado, and introducing me to Amanda over three years ago which I will someday fully express my thanks for. The Conservation Science department and lab group at the Cornell Lab of Ornithology provided me a positive environment to explore my early ideas, and shape my research path as did the friendly environment within the Department of Natural Resources.

This project would not have been possible without the many people I worked with in Guatemala. Most importantly, I want to thank Tara, Rob, John, and Ruth Cahill at Community Cloud Forest Conservation for their logistical help with field research, and their inspiring efforts towards sustainable development in the region. Elvira helped me conduct household surveys with over 40 families in remote villages, as well as drink the over 40 cups of coffee we were offered as we went house to house. There are dozens of young Q'eqchi' women that made the Disney project come to life through their incredible teaching efforts, and knowledge of agroecology. The schoolchildren, and subsistence farmers remained my inspiration throughout my field work, and today as I write. I have a special thanks to give to Nicky and Rick Falck for being my Guatemalan parents, and inviting Amanda and I to their paradise on Atitlan where we heard their fascinating stories of life in Guate. Of course, I am thankful to all of my wonderful field assistants that hiked hundreds of kilometers, completed monotonous veg surveys, entered data, and overall remained positive and humorous as we got

through each day: Hope Batcheller (my fairy diamond), Jack Hruska, John Cahill, Sara Dzielski, Mary Margaret Ferraro, and Daniel Aldana. Lilly Briggs and Ian Pope provided invaluable help and friendship to me as other graduate researchers in Alta Verapaz.

There were several funding sources that made my Master's project possible. The Athena Fund helped me conduct my earliest field work, while the ACSF Sustainable Biodiversity Fund harnessed my interdisciplinary interests which ultimately lead to a larger grant with the 2014 Disney Worldwide Conservation Fund. Through Disney, I was able to include a winter season for migrant monitoring, and three extension projects including environmental education, agricultural development, and a participatory workshop. The EINAUDI International Travel grant supported two round trip flights to Guatemala, and the CALS Alumni Association funded the field gear for my first field season. The Kramer fund supported my summer stipends, and most importantly, the Gates Millennium Scholarship supported my graduate expenses while the Cornell Gates scholars brought an immediate sense of community for me at Cornell.

Without the solidarity I received from the Latin@ Graduate Student Coalition, the Office of Inclusion and Student Engagement, the Cornell Gates Scholars, and the "Women Warriors," I am not sure how I would have gotten through some of the more challenging parts of my graduate career and while current events were taking place around the country and in our lives. Together, we have used our visions to create a shared space on campus to support one another.

Likewise, my Ithaca friends kept me laughing and continually reminded me of the bigger picture. A special shout out goes to Ruth, Chela, Pepe, Justin, Marisol, Katie, Rose, Steven, Zephyr, Maria Jose, Elisa, and Tom. My Colorado friends reminded me not to lose my way especially Vanessa, Gaby, Whitney, Lyndsay, Devon, and Adrienne, and my network at Colorado State University was always there when I needed them.

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TABLE OF CONTENTS

TABLE OF CONTENTS CONTINUED

LIST OF TABLES

LIST OF TABLES CONTINUED

LIST OF FIGURES

LIST OF FIGURES CONTINUED

CHAPTER 1: Thesis Introduction

INTRODUCTION

As the world's natural habitats continue to be converted for human use, integrating conservation within the activities that support sustainable livelihoods will become ever more vital. This goal is especially challenging in areas where high levels of poverty and biodiversity co-occur, because human and wildlife communities generally rely upon the same natural resource base (Lee & Barrett 2000; Chappell et al. 2013). Holding up to three-quarters of the world's biodiversity, the tropics are a prime example, given that only 20% of tropical forests remain often in agricultural landscapes and communities struggling with poverty (McNeely & Scherr 2003; Fisher & Christopher 2007; United Nations 2013; ICSU & ISSC 2015). Conservation of tropical forests, therefore, depends in part on effectively managing agroecosystems to support livelihoods, provide food security, reduce habitat loss and degradation, and protect biodiversity. Fortunately, many governments, researchers, development agencies, and communities recognize the need for multi-functional landscapes, and consequently, a debate has persisted for decades on the best strategies to both "feed the world" and "rescue nature" (Gradwohl & Greenberg 1988; Stone 1991; Greenberg et al. 1997; Green et al. 2005; Borlaug 2007; Perfecto 2009; Amekawa 2011; Altieri & Toledo 2011).

Two contrasting paradigms of biodiversity conservation and sustainable development have recently been articulated – "land-sharing" and "land-sparing," though they are not mutually exclusive. Land-sharing integrates components of native ecosystems (i.e. agroforestry, agroecology) into cultivation systems where low-intensity agricultural practices may better support elements of biological diversity and ecosystem services compared to intensively cultivated systems (Altieri 1995; Perfecto et al. 1996c; Greenberg et al. 1997, 2000; Bakermans et al. 2009; Pywell et al. 2012; McDermott & Rodewald 2014a). Shared land may also incorporate local indigenous knowledge, and

promote diverse agroecosystems such as polycultures (Perfecto 2009; Amekawa 2011; Altieri & Toledo 2011). Land-sparing is an approach that often prioritizes technologically-driven and high yielding food production on some lands while protecting natural and intact habitats elsewhere (Green et al. 2005; Borlaug 2007; Edwards et al. 2010; Balmford et al. 2012; Chandler et al. 2013). Many recent studies have addressed the relative advantages or disadvantages of either approach, contexts within which they have proven successful, and the extent to which the "either-or" framing is useful at all, given that both frameworks may be required to meet conservation and development goals (Egan & Mortensen 2012; Chandler et al. 2013; Fischer et al. 2014; Kremen 2015). Nevertheless, the perception that sparing and sharing may not be compatible continues within the context of some conservation and international development agendas, despite the natural alignment of strategies to conserve resources and alleviate poverty (Lee & Barrett 2000).

Land-sparing has a long history in the conservation and agricultural development fields. One of the most recent and largest land-sparing examples started in the 1960s with Norman Borlaug's "Green Revolution" which was a movement intended to "feed a billion lives" through technological and intensive food production. The technological innovations that came from the movement were incredibly successful at lowering starvation rates (Borlaug 2007), though critics argue the Green Revolution had flawed assumptions with unintentional environmental and social consequences. Perhaps most challenged was the assumption that insufficient food production caused starvation, and as such, increased yields would feed the world – an idea that failed to recognize ***access*** to food as a key contributor to food insecurity (Sen 1984). Also criticized was the claim that the Green Revolution was the "best option to meet the challenges of increasing food production and conserving wildlife" (Borlaug 1997) given that environmental consequences were not sufficiently considered (Tangley 1987; Perfecto 2009; Amekawa 2011; Altieri & Toledo 2011; Gordon et al. 2012; Chappell et al. 2013). Agrochemical use is an excellent example of that shortcoming. Agrochemicals

were effective at increasing food production, but they can also pollute watersheds, degrade soils (Hunke et al. 2015), and negatively impact wildlife populations (Carson et al. 1962; Potts et al. 2010) and human health (Dowdall 2014). From a social perspective, the Green Revolution was criticized for unintentionally fostering dependency upon chemical externalities (Dowdall 2014) and reducing heirloom crop diversity, thus, countering many of the principles of food sovereignty, which is defined as "the right of peoples to healthy and culturally appropriate food produced through ecologically sound and sustainable methods, and their right to define their own food and agriculture systems" (Pimbert 2009).

After the Green Revolution, there was an especially strong push for land-sparing initiatives that better represented a "win-win" between conservation and development outcomes. The "Integrated Conservation Development Projects (ICDPs)" were one such example developed in 1992 by the World Bank and World Wildlife Fund. To better demonstrate win-win solutions, they focused on core protected areas for wildlife, buffer zones for co-existence, and cultivation zones for humans. However, empirical research showed that most ICDPs fell short of wildlife conservation or development goals due to overcomplicated and flawed assumptions (Barrett & Arcese 1995; Brandon 2001). Although land-sparing approaches can be highly effective in some contexts, they cannot be the sole option for biodiversity conservation or agricultural production. Most now understand that multi-functional landscapes created by land-sharing practices can also accommodate human and non-human needs (Greenberg et al. 1997; Green et al. 2005; Perfecto 2009; Bakermans et al. 2011; Kennedy et al. 2011; Pywell et al. 2012; McDermott & Rodewald 2014b).

As such, in the mid-1990s "wildlife-friendly farming," gained popularity as a land-sharing framework supported by evidence that highly-modified land uses (i.e. shaded coffee, cacao, cardamom, etc.) can provide important habitat to wildlife, especially to birds (Perfecto et al. 1996; Greenberg et al. 1997, 2000; Beecher et al. 2002; Bakermans et al. 2011; McDermott & Rodewald

2014a). However, highly-modified land may not retain all elements of biodiversity, especially for large frugivores (Redford 1992). High agro-biodiversity, in terms of wildlife and crops cultivated, can benefit humans through pest-control services provided by migratory birds (Perfecto et al. 2004; Karp et al. 2013), maintenance of ecosystem services including nutrient cycling, water provision, erosion control, and production of more diverse diets. Inevitably, environmentally-conscience agriculture as a model emphasizes the role of farmers in the conservation of biodiversity as they are the managers of the agroecological matrix (Perfecto 2009). All told, a main critique of land-sharing approaches, most strongly from agronomists and some agricultural development practitioners, is that a larger area of land would be required to produce sufficient yields. Though, this idea has been refuted and supported in various studies, leaving the evidence equivocal (Balmford et al. 2005; Perfecto 2009; Altieri 2009; Iverson et al. 2014; Teuscher et al. 2015).

Regardless, the future of productive agroecosystems for wildlife and human communities continues to expand beyond crop yields and now includes a more broad understanding of food sovereignty, and sustainable livelihoods. "Sustainable Livelihoods" (SL) originally emerged as a way to evaluate poverty-alleviation projects and is most generally defined as "the capabilities, assets (including both material and social resources) and activities for a means of living. A livelihood is sustainable when it can cope with and recover from stresses and shocks, maintain or enhance its capabilities and assets, while not undermining the natural resource base" (Conway 1987). The SL approach expanded to include five different capitals or assets to be targeted and diversified in development projects including physical (e.g., infrastructure, tools, inputs), human (e.g., nutrition, education), natural (e.g., biodiversity, land, water, forests), social (e.g., networks, skills, knowledge), and financial (e.g., incomes, loans) (Scoones 1998). The effectiveness of the SL framework has mixed support. While the Millennium Development Goals, "lifted a billion lives out of poverty," (UN 2013), its motivations were primarily top-down with an emphasis on off-farm livelihoods, and progress

towards environmental targets was not as strong (Sachs et al. 2009; Amekawa 2011). As such, Amekawa (2011) and Altieri and Toledo (2011), expand upon the land-sharing and SL frameworks through an agroecological lens to emphasize on-farm livelihoods (i.e. subsistence agriculture as a sustainable way of life) while Perfecto et al. (2009) tie together agriculture, wildlife conservation, and food sovereignty. Collectively, these shared perspectives move toward more socially-just and productive agroecosystems for human and animal communities.

While diverse agroecosystems are widely heralded to benefit people and the environment, there are certain presumed relationships that have relatively scant empirical evidence. For example, higher crop diversity is generally assumed to lead to more nutritious diets, but only recently has a link been established between crop diversity and dietary diversity (see Powell et al. 2015 for 6 of 12 studies establishing relationship). In addition, diverse agroecosystems (i.e., shade coffee) are well-documented to be important wintering habitats for migratory birds, though the same relationship may not be as clear for forest resident species that may become restricted to any remaining forest in the area during breeding periods.

OBJECTIVES

Building upon the SL and land-sharing frameworks, my research examined the relative ability of tropical agroecosystems to support biodiversity conservation and sustainable livelihoods with Q'eqchi' Maya communities in the in the Highlands of Alta Verapaz). I studied habitat use of 15 bird species of conservation concern across six different agroecosystem types (monoculture, polyculture, shaded coffee, pine plantation, secondary forest, and primary cloud forest) and surveyed farmers about their crop diversity, dietary diversity, agrochemical use practices and income generated from crop sales. In this research, I specifically asked three main questions:

1) In what ways can tropical agroecosystems support bird conservation?

2) Which agricultural practices best support sustainable livelihoods in rural communities?

3) Which agroecosystem characteristics most align with the shared goals of promoting healthy human communities and conserving biodiversity?

THESIS LAYOUT

In this chapter, I briefly review the relevant history of land-sparing and land-sharing approaches to wildlife conservation and international development over the past fifty years, as well as a contemporary framework to sustainable rural livelihoods. I also describe two ways I used my findings to inform specific agroecosystem management practices in the Guatemalan Highlands including an agroecological enrichment project, and a participatory conservation workshop. Subsequent chapters are written as manuscripts to be published in international peer-reviewed journals. In Chapter 2, I examined avian occupancy of agroecosystems at local (i.e., microhabitat) and landscape levels and identified the key attributes that promoted habitat use by birds of conservation concern. In Chapter 3, I studied the extent to which the diversity of cultivated and harvested crops supported more varied diets and on-farm income streams for rural communities. Collectively, the three chapters offer a possible contribution to improved bird conservation and sustainable livelihoods in the Highlands of Guatemala by way of advocating for biodiversity-friendly agroecosystems.

CURRENT AND FUTURE RESEARCH APPLICATIONS

In collaboration with a local NGO, Community Cloud Forest Conservation (CCFC), we used our research findings to inform specific agroecosystem management practices in the region through 1) an agroecological enrichment project with over 18 rural Q'eqchi' Maya communities, and 2) a

participatory conservation workshop including over 15 different stakeholder groups. Each component was funded by the 2014 Disney Worldwide Conservation Fund.

Our first engagement project, "Planting seeds for conservation," combined an agroecological and environmental education enrichment program to schoolchildren and their families from Jan 2015-Sept 2015 as a way of improving agroecosystems for communities and conservation. Our ultimate goal was to "plant seeds" that would enrich local diets and bird habitat including nutritious fruits and culturally significant heirloom varieties, and to "plant ideas" through environmental education with the hope of teaching a conservation ethic within the younger generation. Over the course of a four day camp, each of the 18 rural elementary schools completed the Cornell Lab of Ornithology's BirdSleuth curriculum, taught by young women leaders in the region and in their own language, Q'eqchi' Maya. At the end of the program, teachers traveled back to the children's villages with them to plant fruit trees and heirloom crops, while the care and cultivation of each crop (learned during the camp) was reinforced to the parents. Some of our most notable accomplishments included:

- 540 Q'eqchi' schoolchildren, 36 young female teachers, and 70 parents were educated from 18 remote villages in the weeklong program about bird conservation and agroecology (Figure 1.1)
- 1080 fruit trees, and over 40 different crops were planted in polyculture agroecosystems across all villages (Figure 1.2)

The second application from this research was a participatory conservation workshop entitled, "Agroecosistemas para Comunidades y Conservación," held in August 2015 at CCFC with over 15 stakeholder groups, and 75 participants (Figure 1.3). Our aim here was to create a platform that brought together a wide variety of perspectives to the conservation of highland natural resources in Guatemala in order to receive feedback upon our own research, and identify some of

the most leading issues in the region. The full-day workshop was celebratory in nature and used a combination of presentations, breakout discussion groups, and idea-mapping with regards to bird conservation and sustainable development of subsistence communities. During lunch and evening sessions, participants learned about and ate traditional heirloom foods, hiked cloud forest trails, and made new personal and professional connections. The following pressing needs regarding natural resource conservation in the study site were discussed:

a) reducing agrochemical use and pollution to soils and watersheds

b) determining drivers of deforestation of cloud forests

c) improving governance (i.e. corruption in the government)

d) increasing ecological awareness and

e) addressing rapid population growth.

During the idea-mapping activity, participants designed a feasible agroecosystem for birds and people in their small groups and recommended similar themes including polycultures with terracing, agroforestry (i.e. silvopasture, coffee, cacao), corn milpas, integrated secondary vegetation, reforestation plots, and forest fragments (Figure 1.4). A few of the best quotes transcribed from the workshop were:

A local farmer from a nearby village compares small and large scale deforestation:

> Sometimes we focus a lot on communities and people, on how to make them value their forests, when it's actually been proven years ago that it's the great businessmen that are devastating our economic resources. We were talking about the difference between big landowners and villages. The owners of big farms often make a decision for their economic benefit with no ecological conscience and they'll cut down huge stretches of forest, whereas people in villages only cut down small amounts of forest because of their need while the landowners log at a whim. So I think that that's where we can see the difference between big farms who are the greater causers of destruction compared to villages.

An organic farmer and private reserve owner explains ecosystem services of birds:

> From October to mid-April, I don't have to pay anyone to kill all the little caterpillars of the white butterfly; warblers come down and eat them all. I'll tell you that we want to set up a sort of monitoring, a system to control plagues. For me, there is no better indicator of a healthy environment than birds….the place where we are now used to be owned by people [the finqueros] whose policy was [to kill birds], because the chacha [*Ortalis vetula]* would eat the beans or the tzitzop [*Saltator atriceps]* would eat the chiles, etc. We have all these species interacting with astounding liberty. So, there isn't a better indicator for the health of an ecosystem than birds.

A college student explains her agroecosystem design for conservation and communities:

> We combined some ideas, starting with the reduction of monoculture, adding a silvopastoral system, establishing specific areas, this is a model for rural areas of course. We have some pine forest with [many] tree species to give it more biodiversity of nature and creatures and the different bird species. About water, there by the river you can see fish and clean water. And here, we can see a pair of Quetzals flying over it all.

Based on our experiences, we suggest several future research areas that would contribute to efforts promoting bird conservation and sustainable livelihoods in this region. First and foremost, examining the extent to which rare resident and forest specialist birds can use agroecosystems throughout the year is an important gap within wildlife-agroecosystem studies in Guatemala. Many priority species are difficult to study from a logistical standpoint (i.e. low population densities, difficult to identify and detect), and their habitat specialization may be underestimated if they are only monitored during seasons while migrants are present because most residents are not restricted to breeding at that time. On the other hand, threatened endemics including the Ocellated Quail (*Cyrtonyx ocellatus*) are long known to inhabit agricultural areas alongside human settlements. Increased monitoring of endemics and species that apparently use agroecosystems could help guide management practices. Secondly, the consequences of current agricultural development projects to smallholder farmers could be reevaluated specifically regarding the trade-offs (i.e. economic, social, and environmental) of external market integration (i.e. broccoli) and the emphasis on increased yields over diversified food systems. Agroecologically-motivated development strategies that integrate export crops within traditional food systems and focus on a larger diversity of crops may

be better suited especially when led by agrarian communities themselves (i.e. food sovereignty). Additionally, studies of dietary diversity should consider the many external factors that are known to influence diet choice (i.e. power, gender, wealth, health, etc.) as well as how dietary diversity may compare between farmers who do and do not participate in intensive agricultural markets. Lastly, establishing a link between crop and avian diversity on farms may provide additional support towards biodiversity-friendly agroecosystems that support healthy and culturally appropriate diets.

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Figure 1.1: Using the Cornell Lab's BirdSleuth curriculum, 4th and 5th grade children learn about the diversity of highland birds in the Department of Alta Verapaz, Guatemala. *Photo credit CCFC.*

Figure 1.2: Schoolchildren and camp teachers return to their village in the highlands of the Department of Alta Verapaz, Guatemala to plant fruit trees and heirloom crops they learned about during the agroecology and environmental education camp. *Photo credit CCFC.*

Figure 1.3: Group photo of the August 2015 conservation workshop in the Department of Alta Verapaz, Guatemala. Over 15 stakeholder groups and 75 people were in attendance at the CCFC Agroecology Center. *Photo credit Gemara Gifford.*

Figure 1.4: From the idea-mapping activity from the conservation workshop in Alta Verapaz, Guatemala, a Chamelco college student explains her biodiversity-friendly agroecosystem design with terracing, shade coffee, milpa polycultures, fruit trees, and forest trees that support epiphytes. *Photo credit Gemara Gifford.*

CHAPTER 2: Conservation value of tropical agroecosystems to migratory and resident birds in the Guatemalan Highlands

ABSTRACT

Reconciling agricultural production with conservation is an increasingly complex task, especially in regions where high levels of biodiversity and poverty converge. A diverse agricultural matrix integrated with forest remnants is a potentially useful example of a highly modified landscape that can conserve many elements of native biodiversity. Although empirical support for diverse farmland-forest landscapes continues to grow, most studies have been restricted to only a few species or a single season (i.e. migratory species during dry season months). We studied the relative ability of Q'eqchi' Mayan agroecosystem types to support focal resident and migratory birds at local and landscape scales in the Alta Verapaz Highlands of Guatemala, a region known for its remarkable biocultural diversity. Specifically, we examined the use of three forest and three non-forest habitats (monocultures, polycultures, shaded coffee, pine plantations, secondary forest, and primary cloud forest) by six Neotropical migrant, four endemic, and five forest resident bird species across two seasons when many residents are breeding (June-August 2014), and not breeding (January-February 2015). In addition to examining patterns of species richness, we identified habitat associations of individual species using separate single-species, single-season occupancy models. In general, focal species responded most strongly to structural diversity and forest cover within the landscape, with forest residents more linked to diverse habitats (i.e. polycultures, cloud forest), and migrants using simpler habitats (monocultures, semi-shade coffee). Notably, three of four endemics were not forest-associates. Occupancy of focal species was best predicted by canopy cover regardless of habitat specialization, followed by tree density and epiphyte abundance. Landscape composition was especially important for forest-dependent species which were positively correlated to the proportion of cloud forest within 100 hectares. Seasonal patterns of habitat use by several forest-

dependent birds suggests that specialization might be higher in breeding than non-breeding seasons, raising the possibility that previous studies conducted during the non-breeding season may have overestimated their propensity to use agroecosystems. As a whole, our findings indicate that the value of agroecosystems to birds of conservation concern can be improved by retaining >20% canopy cover in farms and >60% in forest habitats, maintaining 150-550 trees/ha, protecting epiphytes, and managing landscapes for 25-40% forest within the matrix. Efforts to plant trees, especially fruit trees and culturally significant heirloom crops, are thus likely to restore or enhance avian habitat within the agricultural matrix.

INTRODUCTION

Conserving biodiversity in working landscapes is inherently complex because of the need to integrate dual needs of conservation and sustainable development, but it becomes particularly challenging in areas where high levels of biodiversity and poverty converge. A growing literature recognizes that, especially within rural working landscapes, conservation and agriculture are unlikely to be achieved exclusively by setting aside land for protected areas and concentrating intensive human activities elsewhere, an approach referred to as "land-sparing" (Waggoner 1996; Balmford et al. 2005; Borlaug 2007). Although land-sparing is a useful approach (Balmford et al. 2005; Edwards et al. 2010; Mahood et al. 2011; Chandler et al. 2013; but see Fischer et al. 2014 or Kremen 2015), effective conservation in working landscapes generally requires multiple strategies because human and wildlife communities depend so heavily upon the same natural resource base for survival (Scoones 1998; Lee & Barrett 2000; Perfecto 2009). As such, "land-sharing" is another useful approach to meet human and wildlife needs as agriculture, in particular, can be practiced less intensively while maintaining natural features that protect ecosystem services (e.g., biodiversity, pest control, water provision) that support agricultural productivity (Conway 1987; Altieri 1995; Greenberg et al. 1997;

Perfecto et al. 2004; Green et al. 2005; Bakermans et al. 2011; McDermott et al. 2015). Indeed, studies have demonstrated that less intensive farming, such as polycultures, reduced soil erosion in the Guatemalan Highlands by 74% (Pope et al. 2015b), and were also associated with higher dietary diversity (Jones et al. 2014; Sibhatu et al. 2015, Chapter 3) and more diverse income streams (Rasul & Thapa 2006, Chapter 3). Thus, environmentally-friendly agricultural practices are likely to be key components of biodiversity conservation in Central America, especially when working towards sustainability, food security, and sovereignty of food systems.

Diverse agroecosystems (e.g., shade-grown coffee) provide excellent examples of how highly modified land can support high levels of the native biodiversity at both local and landscape scales (Perfecto et al. 1996; Greenberg et al. 2000; Vandermeer & Carvajal 2001). Benefits of diverse agroecosystems (i.e. provision of habitat and food sources) have been shown for ants (Perfecto et al. 1996; Philpott et al. 2014), mammals (Harvey & Villalobos 2007), plants (Schulze et al. 2004; Egan & Mortensen 2012), and most widely, birds (Petit et al. 1999; Greenberg et al. 2000; Perfecto et al. 2004; Cruz-Angón et al. 2008; Bakermans et al. 2011; Philpott & Bichier 2012; Hernandez et al. 2013; Karp et al. 2013; McDermott & Rodewald 2014b). Birds are commonly used as indicators for environmental health assessments (Carson et al. 1962; Hitch & Leberg 2007) and can serve as indicators of conservation value of tropical agroecosystems (Bakermans et al. 2011; Chandler et al. 2013; Hernandez et al. 2013). For example, diverse communities of native birds persist in shade coffee (Perfecto et al. 1996c; Greenberg et al. 1997; Bakermans et al. 2011; Philpott & Bichier 2012; Chandler et al. 2013), cacao (Greenberg et al. 2000), organic farmland (Luck & Daily 2003), and silvopastoral systems (McDermott & Rodewald 2014), but less so in simple agroecosystems or intensive monocultures (Greenberg et al. 1997; Cruz-Angón et al. 2008; Azhar et al. 2014). Shade-coffee systems are especially well-documented as important wintering habitats for Neotropical migratory birds (Greenberg et al. 1997; Perfecto et al. 2004; Bakermans et al. 2011; McDermott et al. 2015),

where abundance and species richness can exceed that found in native forest (Petit et al. 1999; Roberts et al. 2000; Bakermans et al. 2009; Hernandez et al. 2013). Not only do birds benefit from the presence of agroforests in the landscape, but shade crops can also benefit from the birds by way of pollination, seed dispersal, and pest management (Şekercioğlu et al. 2004; Hadley 2012). For example, coffee beetle borers *(Hypothenemus hampei*) within coffee plantations declined by 50% when birds were present compared to sites where bird were excluded (Karp et al. 2013).

Several specific attributes of agroecosystems, such as high structural diversity (i.e., high canopy and foliage cover, large trees), and floristic diversity (i.e., plant species richness), have been long associated with high avian diversity and use by conservation-priority species (Greenberg et al. 1997; Petit et al. 1999; Cruz-Angón et al. 2008; Bakermans et al. 2011). Insecticide-free farming is also beneficial to birds because arthropods are available in high abundance as a food resource (Rice & Mclean 1999; Perfecto 2009; Zilverberg et al. 2009). Additionally, migrant and forest birds may be more likely to use agroecosystems with greater densities of trees and epiphytes either because they provide cover from predators (Johnson et al. 2005) or greater foraging opportunities (Cruz-Angón et al. 2008; McDermott et al. 2015). Although local habitat characteristics are important, the value of agroecosystems for conservation may be further improved when located near native forest (Estrada et al. 1997; Roberts et al. 2000) or within heterogeneous landscapes (Vandermeer & Carvajal 2001; Kennedy et al. 2011; Carrara et al. 2015) especially for large frugivorous birds (Redford 1992).

Although empirical support for a diverse agricultural matrix with integrated natural habitats continues to grow, most evaluations have been restricted to only a few species or a single season. Most published studies focus heavily on Neotropical migrants during dry seasons, also the non-breeding stationary period for many residents (e.g., November-March) (Petit et al. 1999; Perfecto et al. 2004; Johnson et al. 2005; Chandler et al. 2013; McDermott & Rodewald 2014b). Relatively fewer studies have examined resident and migrant birds across both wet and dry seasons (Philpott &

Bichier 2012; Hernandez et al. 2013). Restricting a study to a single time frame or species group may not provide useful generalizations for two reasons. First, many migratory species are notably generalist in habitat preferences during non-breeding months of residents (Rappole 1995; Stotz 1996) and often occur in open or intensively managed habitats, as is reported for Gray Catbird (*Dumetella carolinensis*), Indigo Bunting (*Passerina cyanea*), and Black-throated Green Warbler (*Setophaga virens*) in Guatemala (Greenberg et al. 1997) and the Tennessee Warbler (*Oreothlypis peregrine*) in Colombia. Second, the needs of resident species may change throughout their annual cycle. Though some residents breed year-round (Howell & Webb 1995), many Neotropical residents and endemics initiate breeding just as migrants depart – often during wet seasons that extend from late-March through July. In contrast to non-breeding periods when several residents and migrants co-occur in mixed-species flocks and move widely, or have fairly general requirements, resident birds are often more specialized during the breeding season (Karr & Freemark 1983; Loiselle & Blake 1991; Cruz-Angón et al. 2008). For instance, the Common Chlorospingus (*Chlorospingus flavopectus*) reduced use of coffee plantations with fewer epiphytes during the breeding season likely because they rely upon epiphytes for nesting (Johnson et al. 2005; Cruz-Angón et al. 2008). Thus, many studies may overestimate the contribution of agroecosystems to avian conservation if they focus on migratory species alone or miss critical parts of the annual cycle for residents.

Our research addressed these potential limitations by studying migratory and resident species during non-breeding seasons when migrants and residents comingle, and during resident breeding periods when migrants were absent. Specifically, we examined the relative ability of six tropical agroecosystems (monoculture, polyculture, shaded coffee, pine plantation, secondary forest, and primary cloud forest) and their surrounding landscapes to support focal resident and migratory birds. We hypothesized that occupancy by focal species would increase with structural complexity of farms (e.g., canopy cover, tree density) and that this relationship would be strongest

for endemic, high priority migrant, and forest species. However, we expected that resident species would be more restricted in habitat use and less likely to use highly modified habitats during the breeding season. We also predicted that conservation value of agroecosystems would rise with amount of forest in the landscape.

This research was conducted in farmland of Q'eqchi' Mayan communities in the Alta Verapaz Highlands in Guatemala, a region known for its remarkable biocultural diversity (Stepp et al. 2005). From an ecological perspective, the region encompasses two globally recognized Important Bird Areas (IBAs) and is an important wintering location for several migratory species that spend up to seven months on site including the endangered Golden-cheeked Warbler (*Setophaga chrysoparia*), near-threatened Golden-winged Warbler (*Vermivora chrysoptera*), and Wood Thrush (*Hylocichla mustelina*), a watch-list species (Roth et al. 1996). Additionally, both IBAs collectively support 20 restricted-range endemics, and two threatened cloud forest specialists the Highland Guan (*Penelopina nigra*), and Resplendent Quetzal (*Pharomachrus mocinno*). From a human perspective, the area is the homeland of Mayan communities and provides critical food and fiber resources to a population already struggling with some of the highest rates of malnutrition, population growth, exclusion, and poverty in the Western Hemisphere (feedthefuture.org 2011, Chapter 3).

METHODS

Study Area

We studied bird assemblages in the Central Highlands of Guatemala near the city of Cobán in the department of Alta Verapaz (15.4833°N, 90.3667°W). The Central Highlands include several important areas for wildlife conservation including two in our study, the Yalijux and Sacranix Sacred Mountain Ranges (Figure 2.1), both recognized as IBAs by BirdLife International (Birdlife International 2015a, 2015b) and fall within the North Central American Endemic Bird Area (Birdlife

International 2014). The area is home to over 300 bird species, and several of conservation concern (Appendix A). These Sacred Mountain Ranges are biocultural hotspots that contain Mayan ruins, many of which are unexplored, and a variety of sites and attributes that make them important to Highland indigenous communities. The region has been heavily fragmented with a deforestation rate higher than previously thought (and protected areas represent less than 3% of the land use (Birdlife International 2014). Fuelwood extraction for cookstoves and slash-and-burn of secondary vegetation and forest are two important sources of continuing deforestation.

Our three study areas were located within mosaics of agriculture, cloud forest, pine-oak forest, secondary forest, and pine plantations between 1100 and 2300 m in elevation. Annual rainfall fluctuates from 3,000 – 4,000mm not including lateral filtration from clouds (MAGA 2001). Soils are generally poor and highly erodible to the point where the Guatemalan Ministry of Agriculture has classified most Highland soils as non-arable. Nevertheless, hundreds of mountain villages depend on the land for subsistence, and steep slopes cultivated by Q'eqchi' Mayan communities cause additional strain on over-worked land (MAGA 2001). The governmental response has been to implement widespread chemical fertilizer subsidy programs to increase production, in contrast to local non-governmental programs which promote organic soil enrichments using agroecological techniques.

The land-sharing and sparing paradigms provided a useful frame for our study system because traditional Mayan agriculture represents a form of land-sharing including some of the most impressive agroecosystems known (Dunning 1992). The traditional "milpa" is farmed as a polyculture, a practice that has been recorded since pre-Colombian time. In general, a milpa may contain up to 10 distinct varieties of corn and 10 varieties of beans that are intercropped with heirloom squash, chili, as well as deciduous fruit trees including plum, peach, and avocado. Additionally, multiple heirloom vegetables exist within home gardens as well as traditional use of

non-timber forest products for consumption in the household including Roctix (*Cnidoscolus chayamansa*), and Macuy (*Solanum nigrescens*) each found in the cloud forest understory (Chapter 3). Traditional agroecological practices are also widely used today including use of organic fertilizers (i.e. night soils, leaf litter), terracing, and inter-cropping (Nations & Nigh 1980; Demarest 2004). Non-traditional cash-crops, such as shaded coffee and cardamom, are also widely cultivated as polycultures with banana, pacaya palm, avocado, taro, and other plant species, although polycultures within our study region are not as rustic as other agroforestry systems recorded in the tropics (Moguel & Toledo 1999). Colonialism caused a loss of traditional knowledge and a subsequent shift to intensive monocultures devoid of trees or understory vegetation and also simplified existing agroforestry systems (Perfecto et al. 1996; Jha et al. 2014). The use of agrochemicals on milpas has become more common in the last few decades, in part due to intensive cultivation of export vegetables, including broccoli, cabbage, and peas that are grown in the highest of elevations where cash crops and common fruits (i.e., banana, citrus) cannot grow.

Our work focused on three remote villages in the Central Highlands of Guatemala selected because of accessibility and proximity to a local NGO, Community Cloud Forest Conservation (CCFC), an organization dedicated to conservation using a grassroots development approach (Figure 2.1). Focal villages are located within each site and adjacent to the cloud forest, though they varied in the amount of remaining cloud forest. Sanimtaca, the lowest elevation village with a coffee cooperative, was the most forested with a composition of 37% cloud forest, 10% mixed forest and 53% agriculture. Sebob, the highest and most remote village, was the least forested with 15% cloud and mixed forest, and 71% agriculture. Chichen, both a village and a private reserve at CCFC, was more evenly split between forest and agriculture (20% cloud, 29% mixed, and 50% agriculture). The three study areas differed in terms of agricultural practices only in that Sebob, the highest and most remote village, lacked pine plantations and coffee farms. Growing pine is a part of a governmental incentive

program, Programa de Incentivos Forestales (PINFOR), in which landowners are paid to grow and manage pine plantations for local or international trade, though it is inapplicable to landless farmers, or those without documentation of land ownership.

Sampling Design

In total, 142 point count locations were distributed across the three study areas (Chichen, n=65; Sanimtaca, n=40; Sebob, n=37) using a simple systematic stratified design across six agroecosystem types – monoculture, polyculture, shaded coffee, pine plantation, secondary forest, and primary cloud forest (Figure 2.2). The agroecosystem type of each location was classified into one of the six types based on a series of criteria (Table 2.1), such that each point fell entirely within a single agroecosystem type. Points were situated at least 200-m apart using a handheld Garmin GPS unit in WGS 1984 so each point could be revisited by each observer for repeat surveys. Generally, points were surveyed as a trail of 10 to 12 consecutive locations.

We monitored birds at each point count location four times in June-August 2014 (resident breeding season), and five times in January-February 2015 (resident non-breeding season), using a 50-m radius-delimited point count protocol (Ralph, Sauer, & Droege, 1995, MacKenzie et al. 2006). During each point count survey, a single observer recorded the species that were either seen or heard, the number of individuals of each species that were detected, and distance to each bird using a laser range-finder in order to restrict the data to birds within a 50-m radius of each point. Surveys were conducted only when rain, wind, and noise did not substantially impair detection. Surveys were completed during the hours of 0600 and 1200 except for the 2015 sampling season when we added the use of a Neotropical Owl Mobbing Protocol developed by Cornell Lab of Ornithology (Rosenberg et al. unpublished) to improve detection of rare migrants in the morning and an additional afternoon period from 1300 to 1600.

The 2014 monitoring season employed 10-minute passive surveys during the morning period such that each of the 142 point count locations was surveyed four times across four consecutive days. The 2015 monitoring season included both 10-min passive and 16-min owl-mob surveys (10-minute passive period, five minute playback, one minute passive period). On days 1 and 3, only morning passive surveys were used at each point along the trail. On days 2 and 4, owl-mob surveys were used at each point, though only at every other point in the morning (i.e. odd points) separated by passive surveys in between (i.e. even points). Thus, owl-mob surveys were conducted at least 400-m apart. The points not surveyed with owl-mobs in the morning (i.e. even points) were then surveyed with owl-mobs in the afternoon. Each monitoring trail (consisting of 10-12 consecutive locations) was surveyed five times over four consecutive days where each point was surveyed three times with a passive survey (morning only), and two times using the owl-mob protocol (once in the morning, once in the afternoon). To reduce biases that could be introduced to the data due to variation in detection rates among observer and with time of day, we reversed the direction of travel along each monitoring trail and alternated observers so that each location was visited by multiple observers at different times.

All survey data are archived in the Cornell Lab of Ornithology's eBird database, a publicly accessible database of bird observations around the world (Sullivan et al. 2009). Each point count was entered as a single checklist with notes indicating agroecosystem type and type of survey (passive point count, mobbing playback) used.

Vegetation Characteristics

At each point count location, we established four five meter radius subplots for vegetation surveys using a vegetation-description protocol adapted from (Martin et al. 2007). The first subplot was at the center of the 50-m-r point count, while the other three plots were located at either 15, 30,

or 45 meters from the center at zero, 120, of 240 degrees until each distance was used once. Each subplot was divided into quadrates to calculate tree density using the point-centered-quarter method (Mitchell 2007). In each quadrate, the distance to the closest tree was recorded, as well as, species (if known), height, diameter at breast height (DBH), and epiphyte score (1; low to 5; high where > 75% tree was covered) for a total of 16 trees per 50-m radius point count used for calculations. Canopy cover was measured at the center of each subplot using a spherical densitometer, and a 10-factor basal area prism was used to estimate stand basal area, later converted to m^2/ha. Vegetative structure was described within each five meter subplot by visually estimating the percentages of horizontal vegetation cover that occurred within the following subclasses: <1-m, 1-2m, 2-5m, 5-10m, and >10m. For example, within a plot containing a short-statured monoculture, 75% of the vegetative cover could be under one meter, and the remaining 25% found from one to two meters. Other agroecosystems were more stratified, and included a proportion of vegetation in all height subclasses. Subplots were re-surveyed during the 2015 dry season in January and February only if there had been seasonal crop changes (i.e., milpas in the rainy season were usually fallow in the dry season or replaced with broccoli), though this rarely occurred. All metrics presented in this paper and used in analyses were the average values across the four subplots for analyses (Table 2.2).

In addition to the site-level measures described above, several landscape-level metrics were calculated for each survey point. Landscape composition within a 100-ha plot centered on each point count location was quantified from existing land-use maps of the Yalijux and Sacranix mountains which classified the landscape into three classes, 1) primary cloud forest, 2) mixed forest (secondary, pine-oak, pine), and 3) agriculture (Pope et al. 2015a). Distances from the point count center to primary forest, mixed forest, and agriculture were calculated using the "near" function in ArcGIS after clipping out polygons that were smaller than five hectares to exclude small polygon anomalies

from analysis. Coordinates of point count stations were re-projected to WGS 1984 - UTM Zone 15N to match the land-use map from Pope and Harbor et al. (2015a) to ensure accurate planar distance calculation.

Statistical Analyses

Species richness within each of the six agroecosystem types was calculated using an expanded focal species list of migrant, endemic, and forest resident species that included our 15 focal species as well as additional species of conservation concern with <20 detections or detection probabilities too low for occupancy analysis (n = 68, Appendix A). Using our observations from all point count locations, we calculated average apparent species richness for each habitat type by averaging the number of species recorded at points within that habitat category. For each habitat type, the mean and standard deviation of species richness was calculated for each of the following collections of species: migrants, endemics, forest-dependents, and all species (Figure 2.3, Table 2.3).

We examined bird-habitat relationships using single-species occupancy models (Mackenzie 2006) that were fit separately for the data from each season; for our analyses we used package 'unmarked' (Fiske et al. 2015) in the R statistical language (R Core Team 2013). From our expanded focal list of 68 species of conservation concern (Appendix A), only 15 species had sufficient data to estimate detection and occupancy probabilities (i.e., >20 detections during either field season, and with mean detection probabilities >0.15); (MacKenzie et al. 2006). At the same time, we excluded the Wilson's Warbler (*Cardellina pusilla*) and Black-throated Green-Warbler (*Setophaga virens*) from analyses because they occurred at virtually all points. Naive occupancy (i.e. the proportion of sites species was detected) and mean detection probabilities were estimated for each species by combining the detection histories across all three sampling sites (Table 2.4a, 2.4b).

In modeling detection rates, we used four predictors. Detection submodels included both linear and quadratic effects of time of day to account for decreasing bird activity during late morning, and afternoon survey periods, a categorical variable to identify whether a survey was conducted as a passive or owl-mob survey (which attracted birds to the playback), and percent canopy cover. We included canopy cover as a continuous detection covariate in order to account for differences in detection based on habitat structure (Hernandez et al. 2013). Observers' identities were not included in the detection submodel because our preliminary analyses indicated that detection did not vary widely among individuals.

Seven microhabitat and landscape-level predictors were used to model occupancy probability. Occupancy submodels included variables from our vegetation surveys that were manageable on-the-ground, interpretable, and known *a priori* to affect avian occupancy. This included four microhabitat covariates: canopy cover, tree density, understory structure, epiphyte abundance; and three landscape-level predictors: cloud forest and mixed composition in the landscape, and distance to cloud forest (Table 2.5, Figure 2.4).

To estimate probability of occurrence as a function of microhabitat and landscape-level attributes, we created a candidate model set using four detection covariates, and seven occupancy covariates. The candidate model set included 7 univariate occupancy submodels each corresponding to 12 detection submodels ranging in complexity from constant, to one or more detection variables included (i.e. linear and quadratic time, count type, canopy cover)(Appendix B). The quadratic effect of time of day was only ever modeled in conjunction with the linear effect of time of day, and count type was not used as a covariate during the 2014 season because only a passive survey type was used. Occupancy and detection were modeled simultaneously in contrast to a two-step approach (MacKenzie et al. 2006; Mcclure et al. 2012). For species with more than 50 detections, the full candidate model set was used, but otherwise we were restricted to simpler models (i.e. ≤3

covariates) to avoid over-fitting or non-convergence of models (Burnham & Anderson 2002). A breakdown of how the candidate model set was built can be referenced in Appendix B.

Model selection was performed separately for the set of models fit to the data from each species and season. We used the R package, MuMin (Barton 2015), for this purpose. Aikaike's Information Criterion (AIC) was used to rank the set of models in order of parsimony, where models with lower AIC values were better supported by the data. Model weights (Burnham & Anderson 2002) were calculated from AIC values and used as a metric to rank the level of support for each model. Covariates for occupancy and detection were considered to be useful for inference if they were included in the final model subset (<2 ΔAIC of the top model ΔAIC = 0) and if 95% confidence intervals for estimated model parameter values did not include zero (Table 2.6, Figures 2.5-2.6c). A summary of these top-ranked models including beta estimates and their standard errors (for significant relationships between occupancy and covariates) are shown in Appendices B and C for each individual species and season.

RESULTS

Average apparent species richness, based on 68 potential species, was greatest within forest habitats (Table 2.3, Figure 2.3), with significantly more species recorded in primary cloud forest (18 ± 4.94 SD) followed by secondary forest (12 ± 7.01) and pine plantations (11.2 ± 3.22). Migrant species richness was greatest in pine plantations (5 ± 1.49), which included rare migrants (e.g., Golden-winged and Golden-cheeked Warblers) and specialized cloud forest species (e.g., Blue-crowned Chlorophonia and Spotted Woodcreeper). Among non-forest habitats, polycultures had the greatest species richness (10 ± 6.30) comparable to pine and secondary forest. The lowest species richness was found in monocultures (8 ± 3.62), and shaded coffee (7 ± 2.09). Notably, the total number of

species recorded in polycultures was highest among all habitat types, with 61 of our 68 focal species being detected at least once.

For occupancy modeling analyses, each microhabitat and landscape-level feature was significantly correlated with at least one focal species, meaning that the covariate was included in the top-ranked model subset, and estimated model parameters were significant using 95% confidence intervals (Appendix C). For occupancy probability, canopy cover received the most amount of support from the data across species, followed by percent cloud forest within 100 hectares, and then distance to cloud forest (Table 2.6; n = 10, 6, and 4 significant relationships). Tree density, percent height under one meter, epiphyte score, and composition of mixed forest were also significantly correlated to occupancy for two or more species.

We found a significant positive correlation between probabilities of occupancy and structural complexity of habitats (i.e., as measured by higher canopy cover, tree density, epiphyte score, or forest cover in the landscape), for nine species (Table 2.6) and this group included five forest residents (Common Chlorospingus, Grey-breasted Wood-wren, Scaly-throated Foliage-gleaner, Slate-colored Solitaire, and Slate-throated Redstart), two migrants (Black-and-white Warbler, Blue-headed Vireo) and one endemic (Green-throated Mountain-gem). In contrast, two endemics (Blue-and-white Mockingbird, and Rufous-collared Robin) and three migrants (Common Yellowthroat, Gray Catbird, and Lincoln's Sparrow) were negatively correlated with structural complexity of habitats (Table 2.6). The Wood Thrush was positively linked to more complex habitats, however it was only positively correlated to canopy cover at an 85% confidence interval (Table 2.6). One endemic, the Bushy-crested Jay, was not significantly associated with any site-level covariate because it is relatively common at all habitat gradients.

Microhabitat features representing structural complexity of habitat (see above) best predicted focal species occupancy regardless of habitat specialization. Birds that were more

associated with forests or forest-like agroecosystems were positively correlated with canopy cover (Table 2.6), particularly at ranges of 50-75% cover (Figure 2.5: Green-throated Mountain-gem; Figure 2.6a: Black-and-white Warbler; Figure 2.6b: Slate-colored Solitaire, Slate-throated Redstart, Common Chlorospingus, Grey-breasted Wood-wren). However some migrant species (Common Yellowthroat, Lincoln's Sparrow) were negatively correlated with canopy cover and used open areas with <10% cover as is typical of monocultures and simpler polycultures (Figure 2.6a). Higher tree densities, between 150-550 trees/ha common in polycultures and forests, were positively correlated to occupancy for two species (Table 2.6, Figure 2.6a: Blue-headed Vireo; Figure 2.6b: Slate-throated Redstart). The importance of epiphytes varied among seasons, and was positively linked to two species (Slate-colored Solitaire and Grey-breasted Wood-wren) only during breeding season (Table 2.6, Figure 2.6b). Lastly, the proportion of understory height below 1-m was a significant negative effect for two forest-resident species where sites with greater simplicity (i.e. 70% or more vegetation below 1m; non-forest agroecosystems) were less often used (Table 2.6, Figure 2.6b: Common Chlorospingus, Slate-throated Redstart; Ψ <0.5).

In addition to local agroecosystem features, the presence of forest within the landscape was strongly related to habitat use by our focal species. We found support for an effect of the amount of cloud forest within a 100-ha landscape on occupancy for species associated with forests as well as those that tended to avoid them (Table 2.6). For example, predicted occupancy probabilities for forest residents such as Grey-breasted Wood-wren, Scaly-throated Foliage-gleaner, and Slate-colored Solitaire were greatest (Ψ > 0.5) with 10-35% cloud forest in the landscape (Figure 2.6b), whereas the opposite pattern was evident for forest-avoiders Blue-and-white Mockingbird and Rufous-collared Robin (Figure 2.6c, Ψ < 0.5 for sites with>10% cloud forest). Similarly, landscapes with a higher percentage of mixed forest (i.e. secondary, pine-oak, pine), were negatively associated with migrant Gray Catbird (Figure 2.6a) and endemic Rufous-collared Robin, both forest-avoiders (Figure 2.6c).

Distance to forest also was a useful predictor of habitat use for several resident species (Table 2.6). Estimated occupancy probabilities for the Scaly-throated Foliage-gleaner and Slate-colored Solitaire were $\Psi > 0.5$ for sites within 200-m from cloud forest, though the foliage-gleaner had an even tighter requirement where occupancy was predicted at near zero at 50-m or further (Figure 2.6b). In contrast, two human-associated endemics, the Black-and-white Mockingbird and Rufous-collared Robin, more commonly occupied sites at least 300m and 900m from cloud forest respectively (Figure 2.6c).

With the notable exception of endemic species, forest residents seemed to use habitat differently in breeding and non-breeding seasons (Figure 2.6b). Differences in the coefficients for habitat associations appear to be more likely for the Scaly-throated Foliage-gleaner that, despite a general affinity for landscapes containing cloud forest, was found only in close proximity to cloud forest when breeding. Likewise, for the Grey-breasted Wood-wren, we found support for effects of percent cloud forest during the non-breeding season, and only found support for cloud forest to canopy cover and epiphyte score during the breeding season. Although endemic Green-throated Mountain-gem showed support for an effect of canopy cover for both seasons, it was more likely to be found in sites with greater canopy cover during the breeding season.

DISCUSSION

Areas that integrate diverse agroecosystems with natural habitats have been widely promoted to conserve biodiversity in working landscapes (Greenberg et al. 1997; Perfecto 2009), and our work provides additional empirical support to this notion. Nearly all of our focal species used non-forest agroecosystems at some point during the year, and polycultures seemed particularly well-suited for birds probably because they were more structurally diverse with greater canopy cover, densities of trees, and epiphytes. That said, secondary and primary forest habitats were important

for many resident species, possibly more so during breeding periods. Given that our complementary work in this same system indicated that diverse agricultural practices and cloud forest improved human diets and income diversity in the region (Chapter 3), biodiversity-friendly practices that retain forest are likely to contribute to both conservation and sustainable livelihoods in the Guatemalan Highlands.

In general, habitat and landscape attributes that were most important to focal species reflected structural diversity and forest cover within the landscape which aligned with our hypothesis, though particular associations were contrasting between birds using more diverse or simple habitats. Canopy cover was one of the best predictors of avian occupancy regardless of habitat specialization, which is consistent with other studies of agroforestry systems (Greenberg et al. 1997; Rice 1999; Moguel & Toledo 1999; Philpott & Bichier 2012; Mcclure et al. 2012; Wood et al. 2013; Jha et al. 2014; McDermott & Rodewald 2014). That said, migrants were associated with lower levels of canopy than forest residents. High structural complexity is one of the main reasons why shade-grown coffee and other agroforestry schemes are regarded as being beneficial to biodiversity (Harvey & Villalobos 2007; Pywell et al. 2012; Philpott et al. 2014), and especially to birds. Tree species richness, density, and DBH are also known to benefit birds and other wildlife. Our study showed that epiphytes might be especially important for forest residents, like Gray-breasted Wood-wren and Slate-colored Solitaire during the breeding season, a pattern consistent with previous work showing that epiphytes improved the suitability of agroecosystems for other forest residents including Common Chlorospingus (linked to breeding, see Cruz-Angón et al. 2008), and a closely related wood-wren species (Salaman & Coopmans 2003). In fact, forests and agro-forests in the surrounding region of Cobán, Alta Verapaz are globally renowned hotspots for orchid and bromeliad diversity comparable to Ecuadorian cloud forests (Andersohn 2004; Cascante-Marín & Nivia-Ruíz 2012).

Landscapes that integrated agriculture and forest were most used by focal species. Diverse matrices are well known to benefit a wide variety of birds (Vandermeer & Carvajal 2001; Luck & Daily 2003; Perfecto 2009; Kennedy et al. 2011). The value of agroecosystems to conservation has also been shown to rise with the amount of and proximity to forest in the landscape (Estrada et al. 1997; Roberts et al. 2000; Luck & Daily 2003; Perfecto et al. 2009, Carrara et al. 2015). We suspect that landscape context partially explains the unexpectedly low use of coffee by birds in our system, given that coffee was cultivated at farther distances from forest than most other agriculture (Figure 2.4). Deliberate retention of forest to improve the value of agroecosystems to birds is a useful strategy given that only 15-37% of cloud forest remains in the region.

The seasonal patterns of habitat use that we hypothesized and report suggest that forest specialization was greater in breeding than non-breeding season for several forest resident birds. This pattern warrants attention because most studies of agroecosystems and agroforests have occurred during non-breeding periods (i.e. November – March) when habitat associations of Neotropical residents seem to be broader, and many forest residents engage in mixed-species flocks (McDermott et al. 2015, Howell and Webb 1995). Indeed, previous research shows that during breeding periods, Gray-breasted Wood-wren has habitat-mediated courtship behaviors such as duetting (Dingle et al. 2008) similar to our study where wrens were more strongly associated with primary forest and epiphytes when breeding (Figure 2.6c, reference Figure 2.4 epiphyte score), and and participated in mixed-species flocks during non-breeding (Howell and Webb 1995). Likewise, the Common Chlolorspingus appeared to shift towards cloud forest in our study (i.e. a 70% or higher canopy cover requirement) and is known to breed using epiphytes in others studies (Howell and Webb 1995; Cruz-Angón et al. 2008). Thus, studies conducted during non-breeding periods may overestimate the ability of agroecosystems to support forest residents.

Our research has several caveats with regards to bird conservation in Guatemalan agroecosystems. First, there were many conservation priority species that we were not sufficiently monitored because of rarity or low detectability. These low-detection species include endemics like Pink-headed Warbler (*Cardellina versicolor*), Ocellated Quail (*Cyrtonyx ocellatus*), Blue-throated Motmot (*Aspatha gularis*), and Rufous-browed Wren (*Troglodytes rufociliatus*), priority migrants Golden-cheeked Warbler (*Setophaga chrysoparia*), and Golden-winged Warbler (*Vermivora chrysoptera*), and cloud forest specialists including the Resplendent Quetzal (*Pharomachrus mocinno*), and Spotted Nightingale-thrush (*Catharus dryas*) among many others. Inferences from our work are, therefore, limited to relatively common species. Second, although we surveyed across two seasons, we were limited to a single year and during a snapshot of the resident breeding season which generally occurs from late-March through July, though some species are known to breed year-round. Examining species patterns for the whole avian assemblage over multiple years is advisable, given potentially high annual variation in habitat use and low detectability of forest interior species (Philpott & Bichier 2012; Hernandez et al. 2013). Third, while we suggest that some forest resident species seem more restricted to forest during the breeding season, we did not conduct a formal statistical test to examine significant differences in occupancy between seasons which could further support our suggestion for these species.

Our research provides additional support for the idea that working landscapes made up of diverse agroecosystems and forest remnants can contribute to bird conservation. When put into the context of our previous work on sustainable livelihoods (Chapter 3), we find that Mayan polycultures can support development and conservation goals within biodiverse regions struggling with poverty and malnutrition. However, the importance of cloud forests to birds and people in our study system should not be overlooked. Based on our work, the conservation value of agroecosystems can be most improved by retaining >20% canopy cover in farms and >60% in forest habitats, maintaining 150-

550 trees/ha, protecting epiphytes, and managing landscapes for 25-40% forest within the matrix. Recent research within our same study area suggests that a central component to cloud forest conservation may be achieved indirectly through improved soil health on agricultural land because healthier soils would reduce dependency upon slash-and-burn practices, a main driver to deforestation (Pope et al. 2015a). Thus, we suggest that diversified agroecosystems especially with fruit trees, culturally significant heirloom crops, and cloud forest remnants will create or improve avian habitat within the agricultural matrix and support local livelihoods.

Overall, we suggest several next steps towards a sustainable future in the Guatemalan highlands. First, if we are to improve agricultural landscapes for forest-dependent species, full life-cycle habitat associations should be assessed in more depth than at present. Second, rare or hard-to-detect species known should be monitored more rigorously (i.e., expanding longer surveys for more than a year), including the threatened endemics Ocellated Quail and Pink-headed Warbler as well as priority migrants like the Wood Thrush, Golden-cheeked and Golden-winged Warblers. Third, evaluating links among social indicators such as high crop diversity and habitat use by priority bird species may provide additional support for suitable, and socially-conscience agroecosystems for communities and conservation. Fourth, we encourage researchers to engage with local people to implement management recommendations within focal communities. As an extension of our research, we worked with collaborators to reintroduce Mayan heirloom crops, plant fruit trees, and engage stakeholders in participatory discussions about conservation and development within the greater highlands of Guatemala (Chapter 1). Ultimately, identifying and advocating for biodiversity-friendly agroecosystems can contribute to bird conservation in the Guatemalan highlands and align with rural community needs.

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Table 2.1: Guatemalan agroecosystem descriptions and criteria for three non-forest (monocultures, polycultures, shaded coffee) and three-forest types (pine plantation, secondary forest, and primary cloud forest).

Land use	Description
Agriculture - Monoculture	Usually slash-and-burn corn, or sun crops devoid of trees, hedgerows, or other bushes. Vertical vegetation structure is absent with most vegetation at 1 meter or below. Monocultures plots can be small (< 5 ha) or large (> 5ha). common species include Great-tailed Grackle, Common Yellowthroat, and Sparrow sp.
Agriculture - Polyculture	Rich home gardens or corn milpas with > 2 crops, many with fruit trees, sedges, pine trees, cardamom, and inter-cropping with squash and heirloom beans. Vertical vegetation structure is simple to complex with average canopy cover of 20%. Plots are usually small (5-10 ha). Coffee is included as a polyculture, but only when coffee bushes represent < 50% of crops.
Agriculture - Shaded Coffee	Semi-shaded coffee plantations or plots where > 50% of crops are coffee plants. Bushes can be 0.5-3-m tall with a mixture of overstory trees, primarily Inga sp., but also avocado, yucca, Cecropia sp., banana, pacaya and many others. Average canopy cover is 20%, plot sizes range from small (< 5 ha) to large (> 40 ha).
Forest - Pine Plantation	PINFOR* pine plantations with a single native pine tree, *Pinus maximinoi*, or sometimes mixed up to 20% with natural trees such as sweet gum or oak. Pine plantations are small (< 5 ha) to large (> 40 ha) and trees may be young, middle, or old age with an average canopy height of 15-m and DBH of 25-cm. The understory is relatively lush with nightshade family, melastomatacea, and other woody plants. Common species include White-naped Brush-finch and Black-and-white Warbler.
Forest - Secondary forest	Younger forest with high tree density. Canopy height usually between 5-m and 20-m, DBH 15-25 cm, and canopy cover > 50%. Sometimes secondary forest is a brushy secondary ag-regrowth that is 5 years or older. Common species include the Orange-billed Nightingale Thrush or Plain Wren.
Forest - Primary cloud forest	Large oak trees, high epiphyte scores, and hanging vines. Average canopy height 25-m, DBH usually 25-35 cm and canopy cover > 75%. Cloud forest specialist species include the Blue-crowned Cholorphonia, Grey-breasted Wood-wren, Blue-throated Mot Mot among others.

Table 2.2: Mean and standard deviation of microhabitat and landscape attributes quantified for six agroecosystems across 142 point count locations in the Department of Alta Verapaz, Guatemala.

Covariate	NON-FOREST HABITAT						FOREST HABITAT					
	Monoculture n = 14		Polyculture n = 41		Coffee n = 16		Pine n = 20		Secondary n = 26		Primary n = 25	
	Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*
Trees/ha	10.46	10.7	89.3	153.31	75.08	53.16	600.22	406.52	418.65	265.75	706.3	547.86
Mean Canopy Height (m)	2.26	1.72	3.96	3.46	3.83	1.62	10.76	4.2	8.62	4.84	16.38	3.73
Mean DBH (cm)	17.57	9.62	14.99	4.88	18.17	5.09	15.78	5.82	13.57	3.94	18.47	4.47
Epiphyte score (0 to 5)	2.71	3.67	5.68	7.95	5.63	4.76	3.37	3.13	8.92	8.07	28.38	14.33
Distance to cloud forest (m)	296.97	166.54	418.71	239.38	504	167.39	246.63	156.35	411.06	344.07	18.1	54.6
Distance to cloud or mixed forest (m)	184.98	105.75	252.58	182.79	314.47	199.3	74.81	100.66	218.08	235.08	14.91	54.17
Percent cover by:												
canopy	5.71	6.75	19.01	13.74	17.42	10.05	43.86	8.98	53.22	19.2	71.15	9.69
woody vegetation	2.35	2.48	5.74	4.57	3.63	2.27	10.07	3.05	14.48	6.19	18.06	5.12
leaf litter	23.75	12.89	15.91	9.43	38.36	12.88	21.36	9.57	24.35	13.61	38	14.55
crop	13.72	8.37	10.64	7.89	13.05	7.2	0.46	1.17	0	0	0.1	0.49
vegetation	57.68	12.88	67.88	14.01	48.75	13.39	76.75	10.12	66.6	13.87	55.02	11.58
bare ground/rock	18.57	11.16	16.21	10.31	12.89	6.72	1.89	1.94	9.05	6.67	6.99	8.48
vegetation below 5m	99.03	1.26	96.44	3.15	97.31	2.19	89.71	4.21	89.94	3.79	83.22	4
mixed forest in 100-ha	15.04	10.66	14.75	7.11	16.99	8.45	29.67	16.83	13.64	6.32	20.68	11.18
cloud forest in 100-ha	12.52	9.03	9.87	10.26	3.31	8.21	13.95	7.61	15.94	17.22	43.38	19.3

Table 2.3: Mean (SD) apparent avian species richness by agroecosystem type and species guild (migrant, endemic, forest). Data are represented in Figure 2.3.

SPECIES RICHNESS

Guild	Monoculture		Polyculture		Coffee		Pine		Secondary		Primary	
Migrant	3.6	(1.6)	3.9	(2.4)	3.3	(1.4)	5.0	(1.5)	3.1	(1.7)	2.3	(1.2)
Endemic	1.5	(0.7)	1.7	(1.1)	1.4	(0.5)	1.3	(0.7)	1.5	(1.2)	2.0	(1.3)
Forest	2.9	(2.7)	4.5	(3.7)	2.0	(1.1)	5.0	(2.5)	7.7	(5.1)	14.1	(3.9)
Total	7.9	(3.6)	10.1	(6.3)	6.7	(2.1)	11.2	(3.2)	12.2	(7.0)	18.4	(4.9)

Table 2.4a: Breeding season (June-August 2014) focal avian species and their total number of detections (n), naïve occupancy estimates, passive detection rates, and associated SE and confidence intervals.

Common Name	Scientific Name	n	Ψ_{naive}	SE	95% CI_{lower}	95% CI_{upper}	$p_{passive}$	SE	95% CI_{lower}	95% CI_{upper}
Blue-and-white Mockingbird	*Melanotis hypoleucus*	45	0.320	0.062	0.213	0.451	0.256	0.052	0.167	0.370
Bushy-crested Jay	*Cyanocorax melanocyaneus*	61	0.489	0.089	0.323	0.658	0.198	0.036	0.137	0.279
Common Cholorospingus	*Chlorospingus flavopectus*	95	0.249	0.037	0.183	0.329	0.584	0.042	0.500	0.663
Gray-breasted Wood-wren	*Henicorhina leucophrys*	127	0.376	0.043	0.296	0.464	0.517	0.036	0.447	0.587
Green-throated Mountain-gem	*Lampornis viridipallens*	18	0.140	0.054	0.064	0.281	0.164	0.051	0.086	0.290
Rufous-collared Robin*	*Turdus rufitorques*	17	0.114	0.034	0.062	0.199	0.333	0.102	0.169	0.551
Slate-colored Solitaire	*Myadestes unicolor*	90	0.226	0.038	0.160	0.308	0.480	0.041	0.401	0.560
Slate-throated Redstart	*Myioborus miniatus*	83	0.350	0.045	0.266	0.443	0.421	0.043	0.339	0.507
Scaly-throated Foliage-gleaner	*Anabacerthia variegaticeps*	41	0.175	0.040	0.109	0.268	0.317	0.052	0.225	0.426

*Indicates species had less than 20 detections but was included because of conservation importance as endemic.

Ψ = probability that a survey site is occupied by focal species.

p = probability each focal species is detected at survey site given that the site is occupied, either a passive survey or an owl-mob survey.

Table 2.4b: Non-breeding season (January-Februrary 2015) focal avian species and their total number of detections (n), naïve occupancy estimates, passive detection rates, owl-mob detection rates and associated SE and confidence intervals.

Common Name	Scientific Name	n	Ψ_{naive}	SE	95% CI_{lower}	95% CI_{upper}	$p_{passive}$	SE	95% CI_{lower}	95% CI_{upper}	p_{owl}	SE	95% CI_{lower}	95% CI_{upper}
Blue-and-white Mockingbird	*Melanotis hypoleucus*	22	0.347	0.177	0.104	0.710	0.084	0.057	0.021	0.284	0.130	0.075	0.021	0.284
Black-and-white Warbler	*Mniotilta varia*	31	0.609	0.259	0.156	0.929	0.037	0.020	0.013	0.103	0.133	0.061	0.013	0.103
Bushy-crested Jay	*Cyanocorax melanocyaneus*	96	0.755	0.101	0.514	0.900	0.190	0.029	0.139	0.253	0.174	0.034	0.139	0.253
Blue-headed Vireo	*Vireo solitarius*	30	0.623	0.273	0.145	0.941	0.035	0.018	0.013	0.095	0.124	0.060	0.013	0.095
Common Cholorospingus	*Chlorospingus flavopectus*	107	0.399	0.046	0.312	0.492	0.399	0.042	0.319	0.484	0.432	0.054	0.319	0.484
Common Yellowthroat	*Geothlypis trichas*	23	0.139	0.042	0.075	0.244	0.211	0.061	0.116	0.354	0.236	0.086	0.116	0.354
Gray-breasted Wood wren	*Henicorhina leucophrys*	128	0.500	0.052	0.400	0.600	0.368	0.036	0.300	0.441	0.359	0.047	0.300	0.441
Gray Catbird	*Dumetella carolinensis*	55	0.462	0.086	0.304	0.629	0.142	0.038	0.083	0.232	0.242	0.053	0.083	0.232
Green-throated Mountain-gem	*Lampornis viridipallens*	62	0.300	0.051	0.210	0.408	0.267	0.043	0.192	0.358	0.314	0.063	0.192	0.358
Lincoln's Sparrow	*Melospiza lincolnii*	25	0.187	0.051	0.107	0.308	0.200	0.072	0.094	0.377	0.253	0.079	0.094	0.377
Rufous-collared Robin*	*Turdus rufitorques*	12	0.150	0.081	0.048	0.378	0.098	0.071	0.022	0.344	0.171	0.103	0.022	0.344
Slate-colored Solitaire	*Myadestes unicolor*	41	0.275	0.065	0.166	0.419	0.257	0.048	0.175	0.361	0.055	0.029	0.175	0.361
Slate-throated Redstart	*Myioborus miniatus*	141	0.756	0.065	0.609	0.860	0.241	0.029	0.190	0.301	0.325	0.040	0.190	0.301
Scaly-throated Foliage-gleaner	*Anabacerthia variegaticeps*	22	0.184	0.060	0.094	0.329	0.194	0.060	0.101	0.339	0.119	0.055	0.101	0.339
Wood Thrush	*Hylocichla mustelina*	25	0.397	0.157	0.154	0.704	0.071	0.031	0.029	0.163	0.121	0.056	0.029	0.163

*Indicates species had less than 20 detections but was included because of conservation importance as endemic.

Ψ = probability that a survey site is occupied by focal species.

p = probability each focal species is detected at survey site given that the site is occupied, either a passive survey or an owl-mob survey.

Table 2.5: Microhabitat and landscape covariates used in candidate occupancy and detection models for 15 focal avian species. Submodels used for each species are listed in Appendix D.

Sub model	Covariate	ID	Scale
Ψ	Tree density (ha)	TD	Microhabitat
Ψ	Canopy Cover (0-100%)	CC	Microhabitat
Ψ	Percent vegetation height under 1m	VH	Microhabitat
Ψ	Total epiphyte score across 16 trees from point-centered quarter	ES	Microhabitat
Ψ	Percent cloud forest in 100-ha	PC	Landscape
Ψ	Percent mixed forest in 100-ha	PM	Landscape
Ψ	Distance to cloud forest fragment > 5ha	DC	Landscape
p	Time of day	T	–
p	$(\text{Time of day})^2$	T^2	–
p	Count type (passive or owl)	CT	–
p	Canopy Cover (0-100%)	CC	–

Ψ = Covariate included in occupancy sub model, always modeled univariate
p = Covariate included in detection sub model, TD^2 is always modeled with TD

Table 2.6: Table of effects on occupancy (Ψ) and detection probabilities (p) for covariates for 15 focal species. Reference Figure 2.6 for associated β and SE estimates for each relationship.

Focal Species	Scientific Name	Guild	Occupancy Probability (Ψ) Response to Covariate							Detection Probability (*p*) Response to Covariate			
			Trees/ha	Canopy cover	% Height under 1m	Epiphyte score	% Cloud forest in 100-ha	% Mixed forest in 100-ha	Dist. (m) to cloud forest	Time of day	Time of day^2	Count type	Canopy cover
NON-BREEDING SEASON													
Black-and-white Warbler	*Mniotilta varia*	Migrant		+								−	
Blue-and-white Mockingbird	*Melanotis hypoleucus*	Endemic					−		+				
Blue-headed Vireo	*Vireo solitarius*	Migrant	+									−	−
Bushy-crested Jay	*Cyanocorax melanocyaneus*	Endemic								+			
Common Cholorospingus	*Chlorospingus flavopectus*	Forest			−								+
Common Yellowthroat	*Geothlypis trichas*	Migrant		−									
Gray Catbird	*Dumetella carolinensis*	Migrant						−					−
Grey-breasted Wood-wren	*Henicorhina leucophrys*	Forest					+						+
Green-throated Mountain-gem	*Lampornis viridipallens*	Endemic		+									+
Lincoln's Sparrow	*Melospiza lincolnii*	Migrant		−									
Rufous-collared Robin	*Turdus rufitorques*	Endemic						−					
Scaly-throated Foliage-gleaner	*Anabacerthia variegaticeps*	Forest					+						
Slate-colored Solitaire	*Myadestes unicolor*	Forest		+								+	
Slate-throated Redstart	*Myioborus miniatus*	Forest		[+]									
Wood Thrush	*Hylocichla mustelina*	Migrant		[+]									[+]
BREEDING SEASON													
Blue-and-white Mockingbird	*Melanotis hypoleucus*	Endemic					−			−	+		
Bushy-crested Jay	*Cyanocorax melanocyaneus*	Endemic	[+]							+			
Common Cholorospingus	*Chlorospingus flavopectus*	Forest		+									
Grey-breasted Wood-wren	*Henicorhina leucophrys*	Forest		+		+							+
Green-throated Mountain-gem	*Lampornis viridipallens*	Endemic		+						−			
Rufous-collared Robin	*Turdus rufitorques*	Endemic					−		+				
Scaly-throated Foliage-gleaner	*Anabacerthia variegaticeps*	Forest							−				
Slate-colored Solitaire	*Myadestes unicolor*	Forest				+	+		−	−	+		+
Slate-throated Redstart	*Myioborus miniatus*	Forest	+		−								
	Total top-ranked models		*3*	*10*	*2*	*2*	*6*	*2*	*4*	*5*	*2*	*3*	*8*

+ indicates a significant positive relationship between the covariate and corresponding parameter based on 95% confidence limits and the model <2ΔAIC$_c$.
- indicates a significant negative relationship between the covariate and corresponding parameter based on 95% confidence limits and the model <2ΔAIC$_c$.
[ ] brackets indicate rare cases where the only significant covariates for the species was at the 85% confidence level.

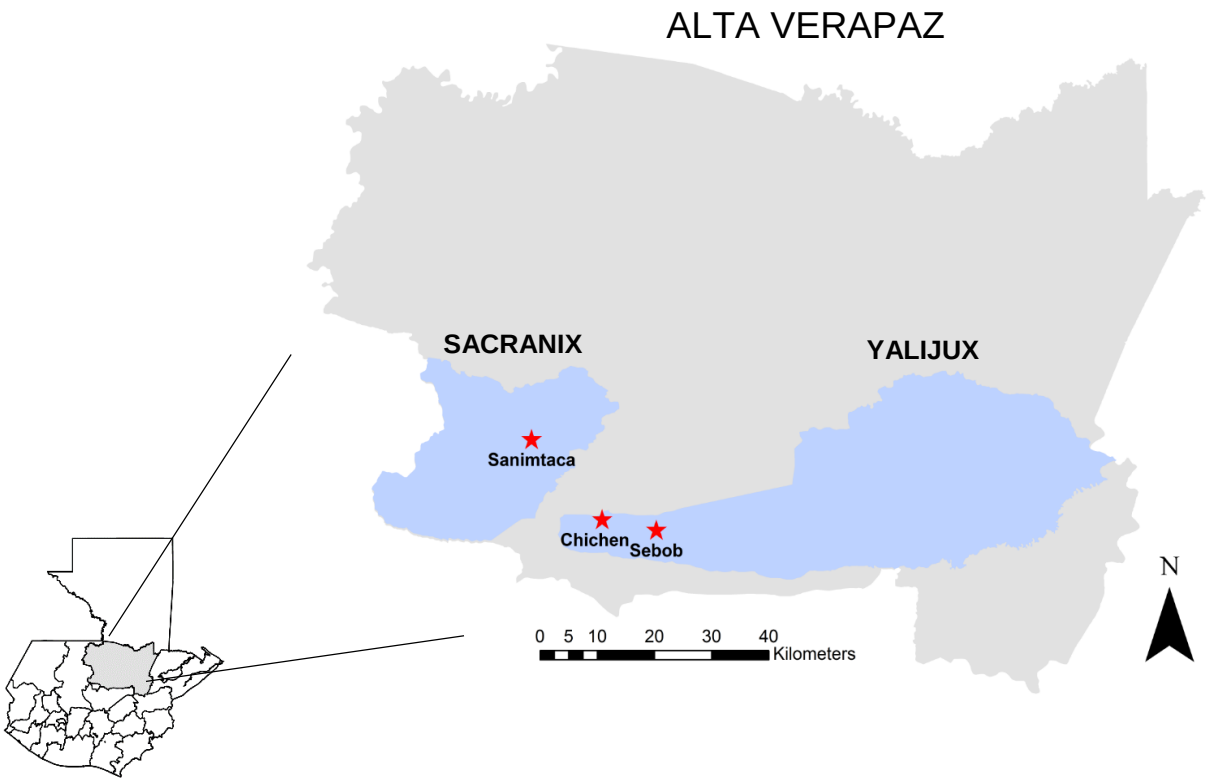


Figure 2.1: Study area in the Department of Alta Verapaz, Guatemala, two Important Bird Areas, the Sacranix and Yalijux mountain ranges, and three village sites, Sanimtaca, Chichen, and Sebob.

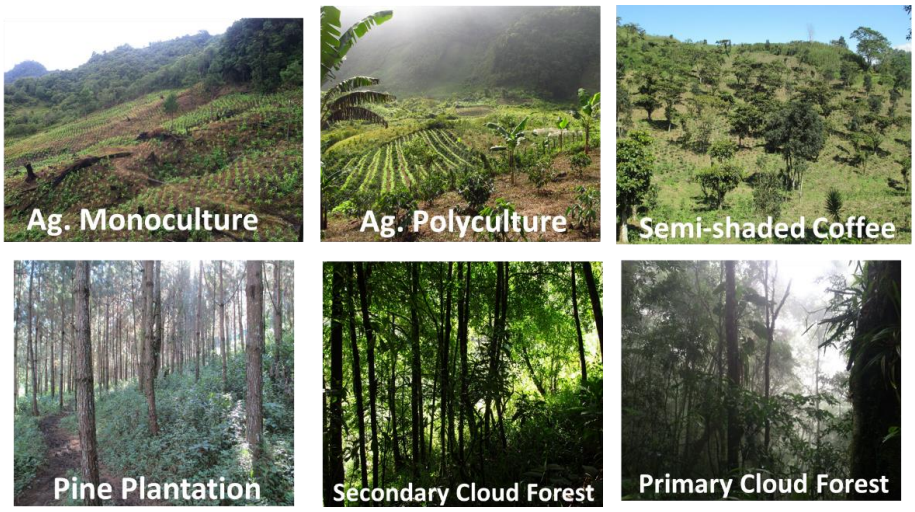


Figure 2.2: Photos of each agroecosystem type surveyed: monoculture, polyculture, shaded coffee, pine plantation, secondary forest, primary forest.

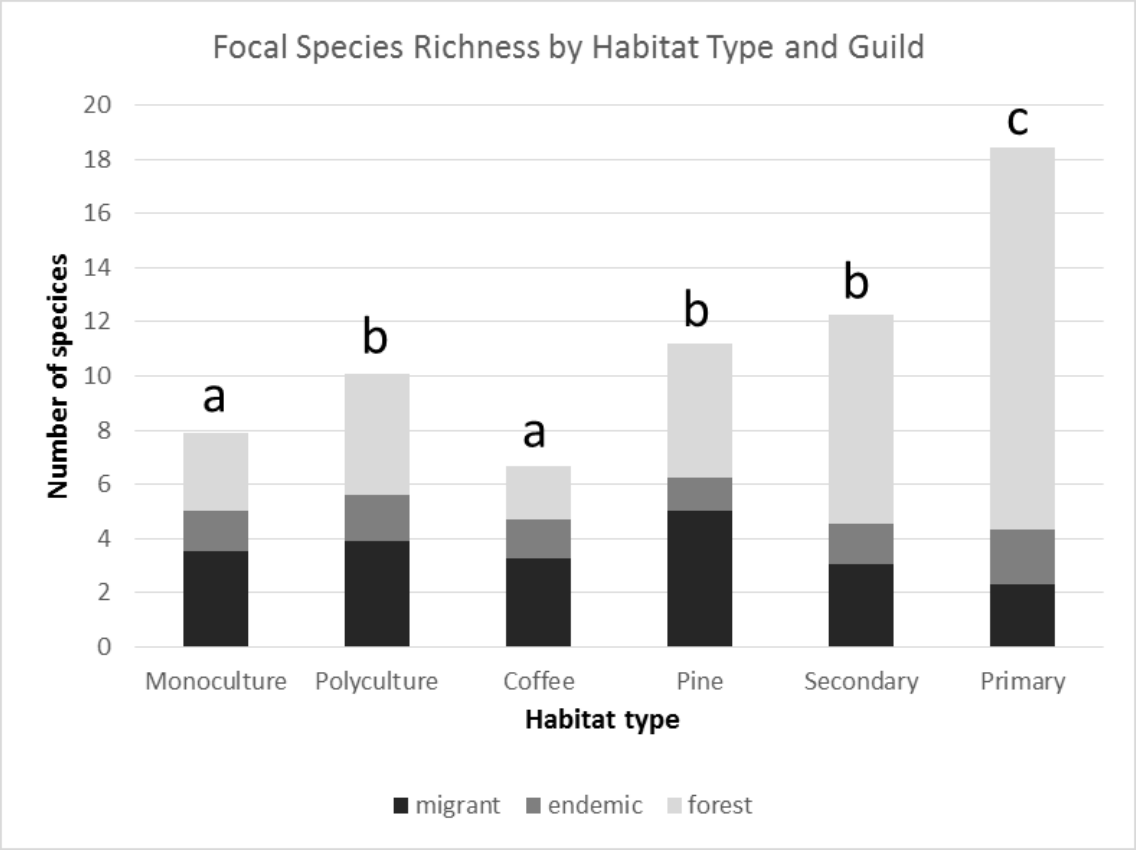


Figure 2.3: Mean apparent avian species richness by agroecosystem type and species guild (migrant, endemic, forest) in the Department of Alta Verapaz, Guatemala. Polyculture has the highest species richness of non-forest agroecosystems. Reference Table 2.3 for mean and SD values for each species guild. Reference Table 2.3 for mean and SD values for each species guild. Matching letters indicate no significant difference in total species richness based on 95% confidence intervals.

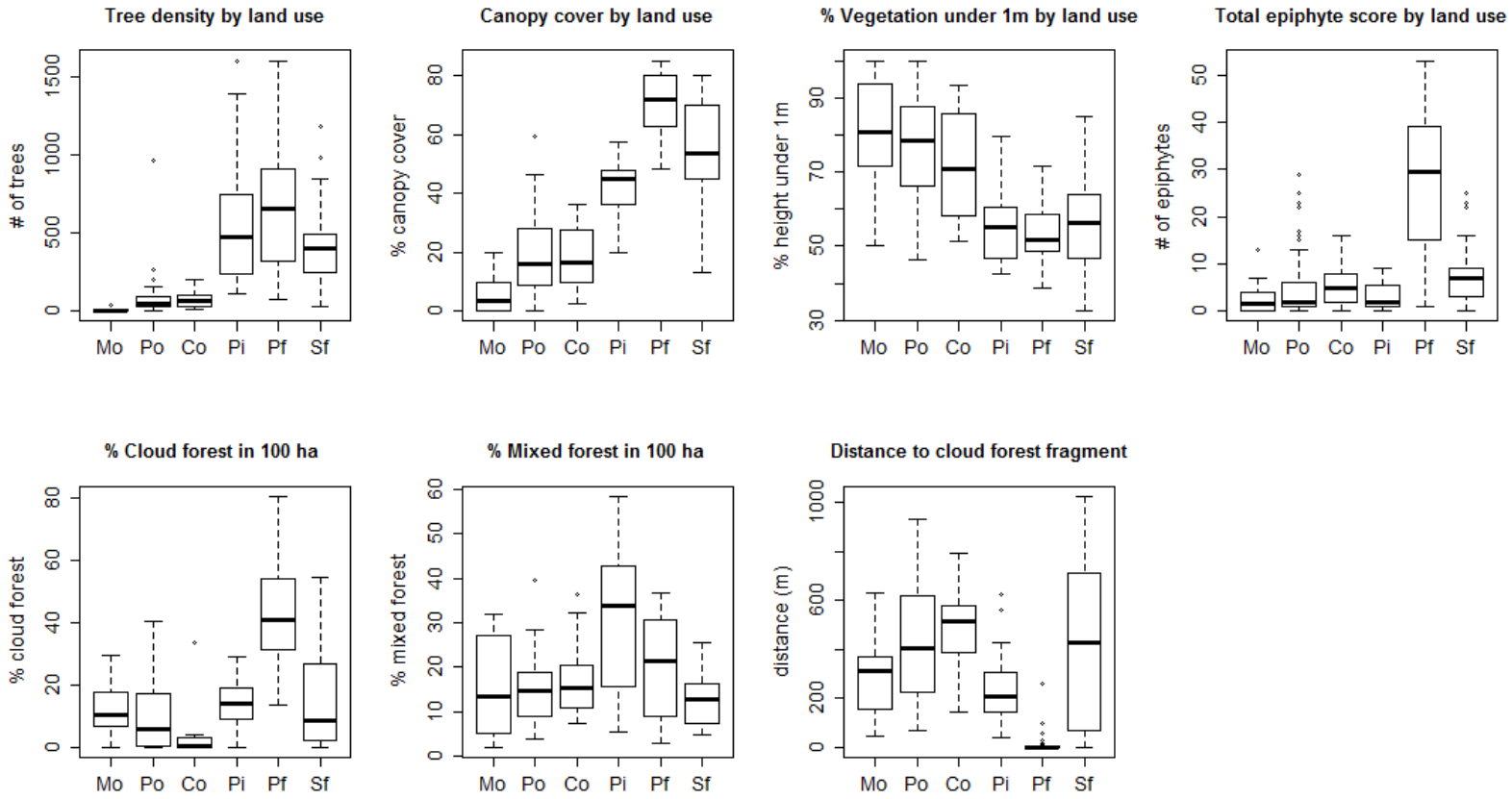


Figure 2.4: Median and variance of modeled microhabitat and landscape features of six tropical agroecosystem types. Mo = monocultures, Po = polycultures, Co = coffee, Pi = pine plantation, Pf = primary forest, Sf = Secondary forest.

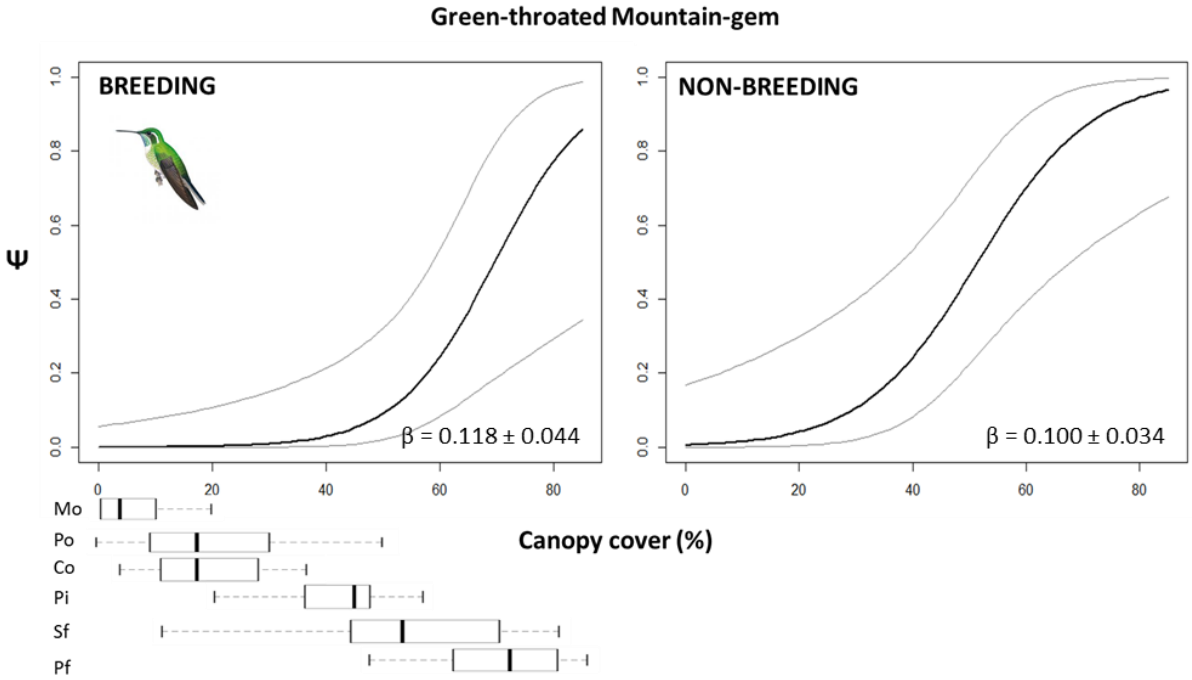


Figure 2.5: Relationship between the predicted estimates of occupancy probability (Ψ) and canopy cover of the Green-throated Mountain-gem in the highlands of the Department of Alta Verapaz, Guatemala, June – August 2014 (breeding) and January – February 2015 (non-breeding). The significant breeding model was Ψ(canopy cover) *p*(Time of Day) while non-breeding was Ψ(canopy cover) *p*(canopy cover). Beta estimates and 95% CI of Ψ(canopy cover) are noted. Note: breeding season has been recorded from March-April, and June-July (Howell and Webb 1995).

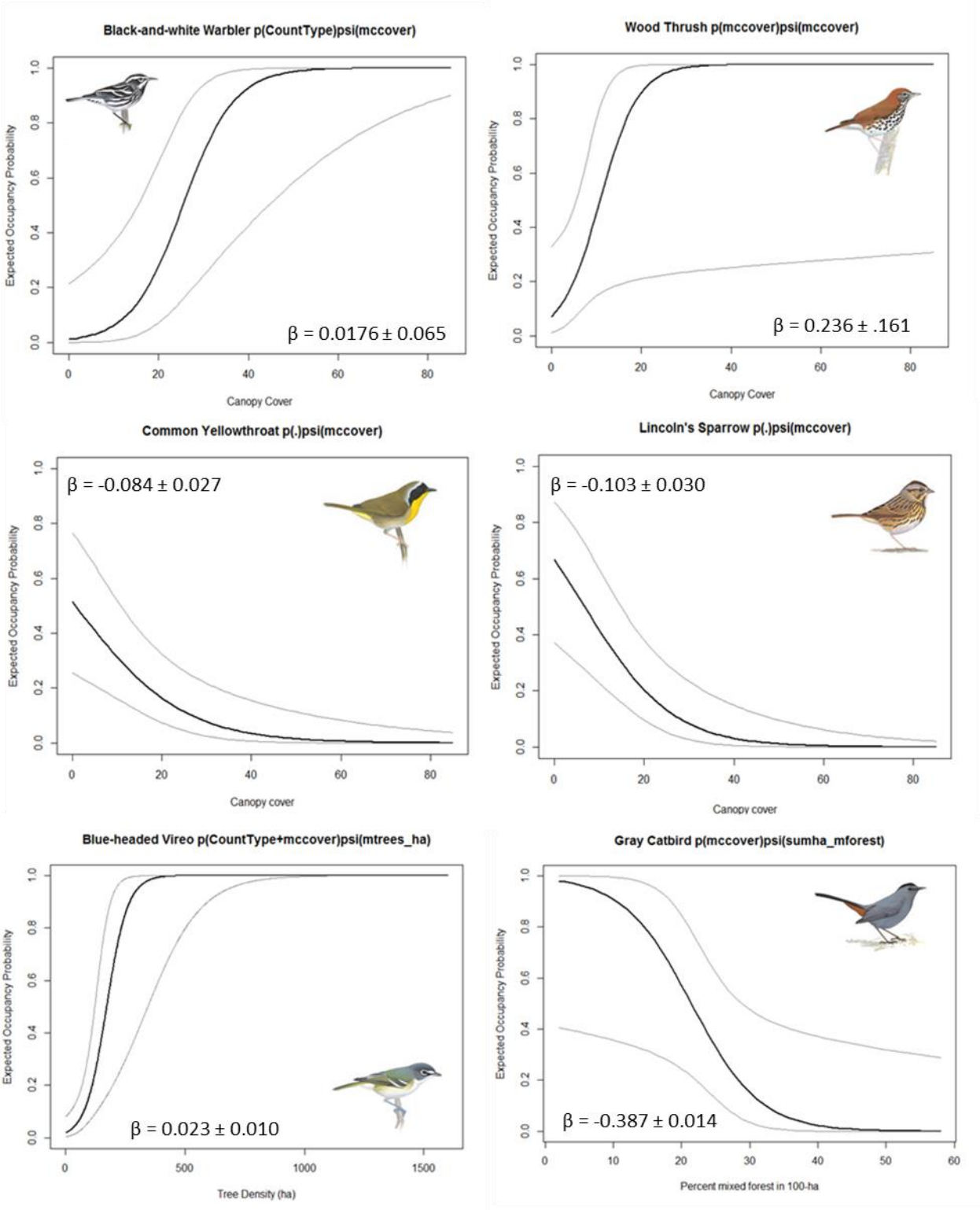


Figure 2.6a: Relationship between the predicted estimates of occupancy probability (Ψ) and habitat covariates within the top model subset of each migrant species wintering in the highlands of the Department of Alta Verapaz, Guatemala, January – February 2015 (non-breeding). Beta estimates and 95% CI of significant occupancy covariates are noted.

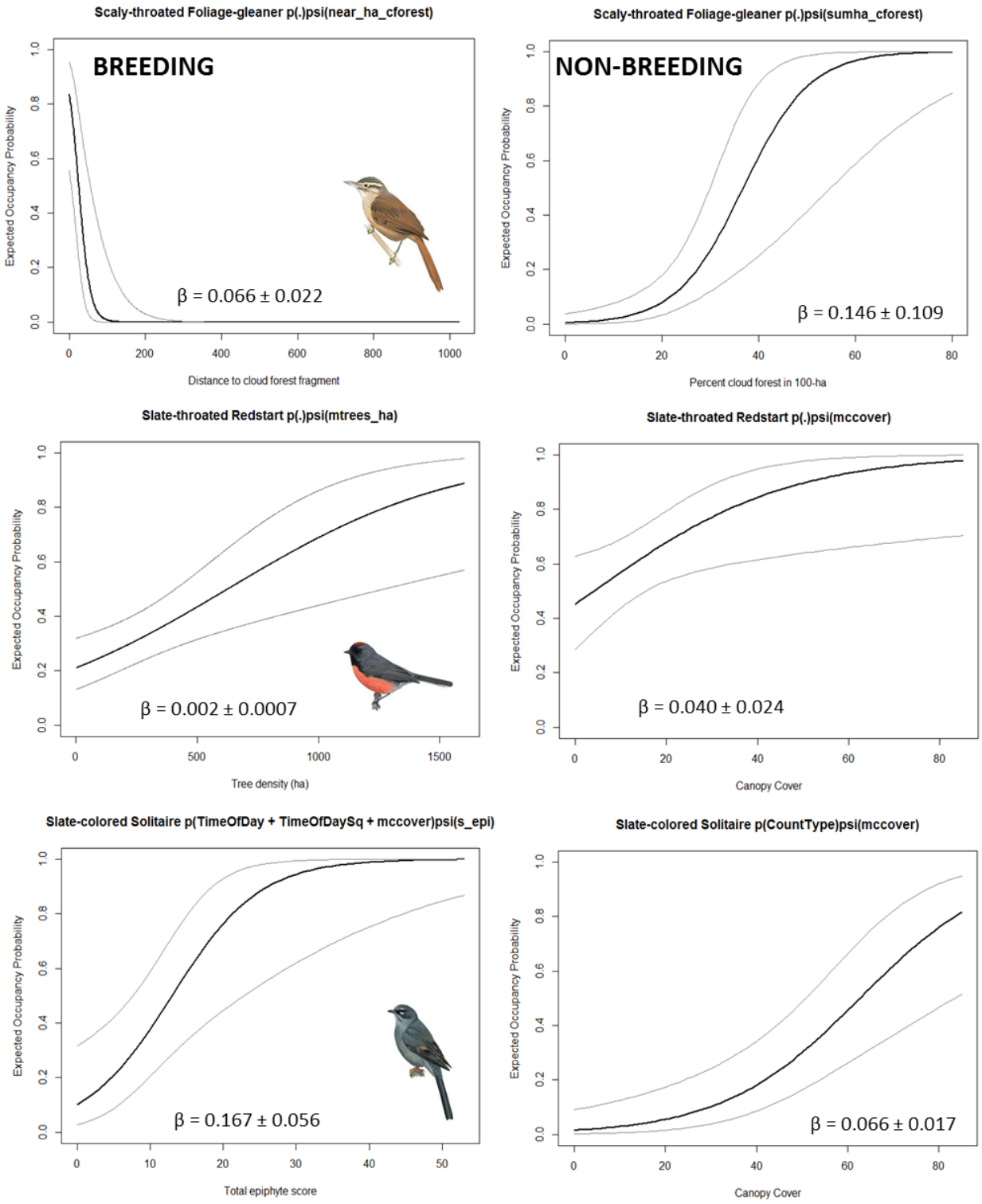
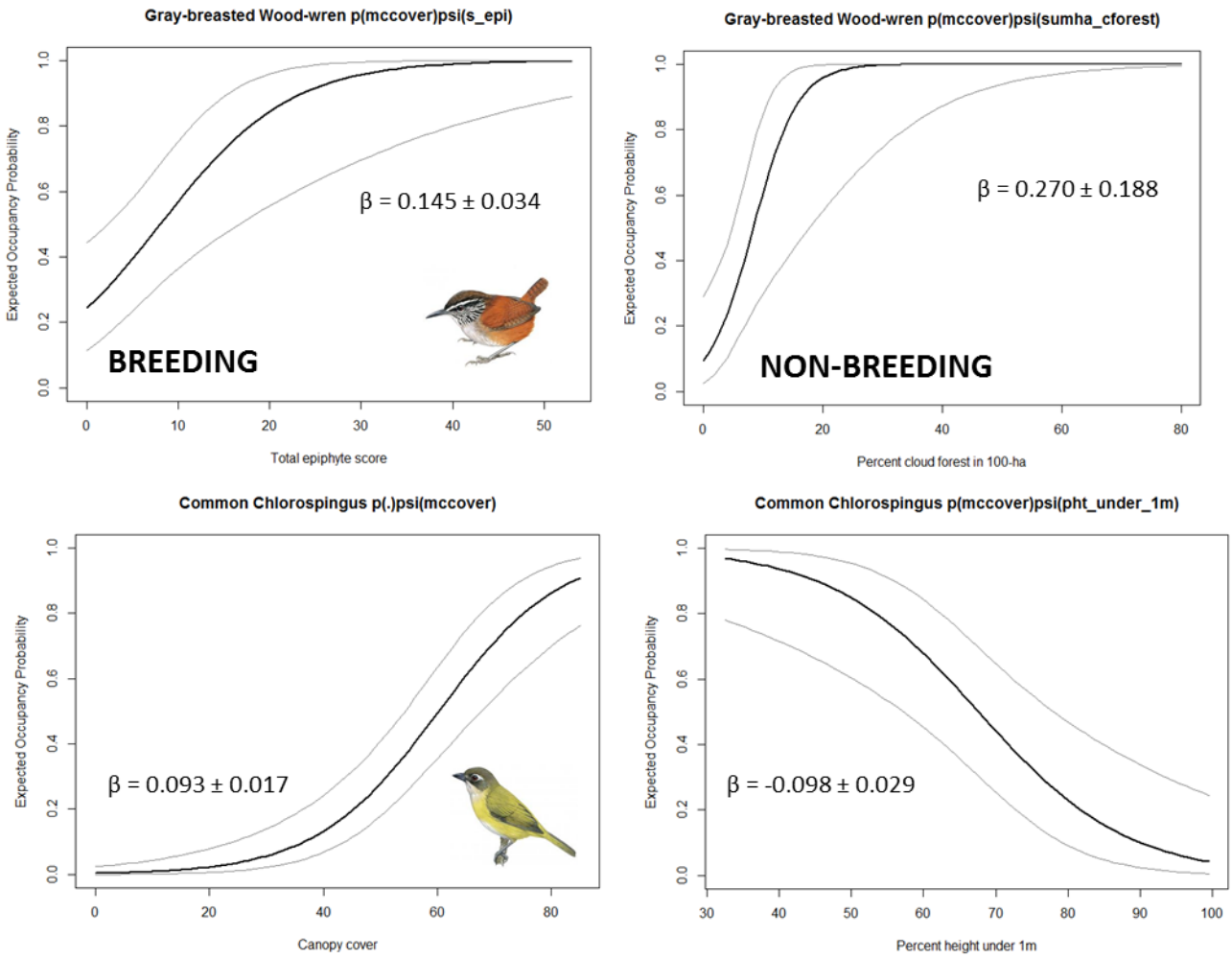


Figure 2.6b: Relationship between predicted estimates of occupancy probability (Ψ) and habitat covariates within the top model subset of each forest resident in the highlands of the Department of Alta Verapaz, Guatemala, June – August 2014 (breeding) and January – February 2015 (non-breeding). Note: breeding season for Slate-colored Solitaire is unknown. Beta estimates and 95% CI of significant occupancy covariates are noted.

Figure 2.6b continued:



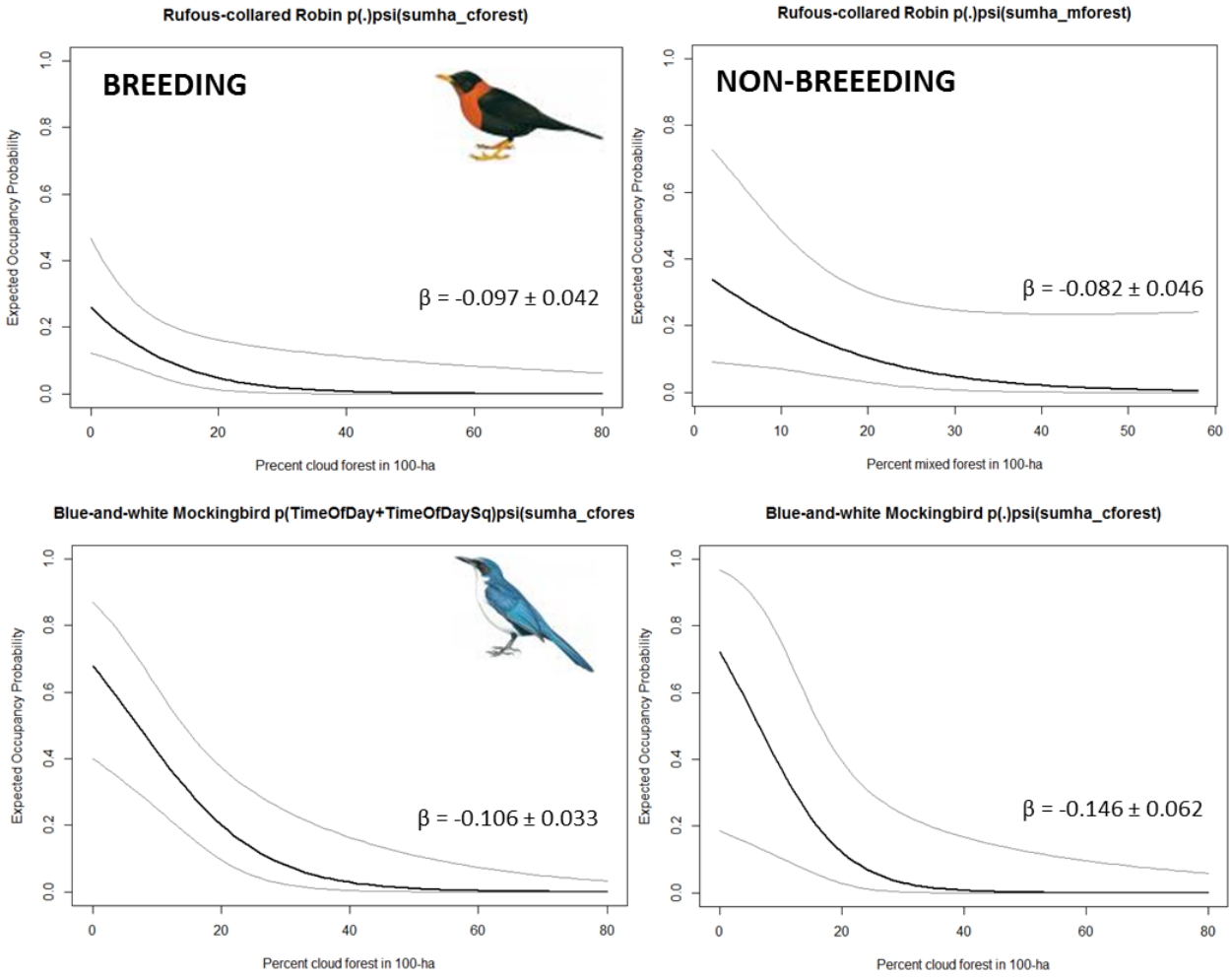


Figure 2.6c: Relationship between predicted estimates of occupancy probability (Ψ) and habitat covariates within the top model subset for each endemic species in the highlands of the Department of Alta Verapaz, Guatemala, June – August 2014 (breeding) and January – February 2015 (non-breeding). Note: Recorded breeding season for Rufous-collared Robin (April-May) may not overlap with our survey period. Beta estimates and 95% CI of significant occupancy covariates are noted.

CHAPTER 3: Biodiversity conservation and sustainable livelihoods in Guatemalan agroecosystems

ABSTRACT

As the world's natural habitats continue to be converted for human use, integrating biodiversity conservation within the activities that support sustainable livelihoods becomes even more vital. Promotion of diverse agroecosystems with interspersed farmed and natural habitats has been one successful approach to achieve multiple human and environmental targets. Drawing from the Sustainable Livelihoods (SL) framework, we examined the extent to which the diversity of crops harvested or grown supported diverse household diets (i.e., human capital) and on-farm income streams (i.e., financial capital). Household dietary diversity is a widely accepted indicator of nutritional status while on-farm income diversification is known to alleviate poverty and promote food sovereignty by reducing dependence upon externalities. We studied rural Q'eqchi' Mayan communities in the Department of Alta Verapaz, Guatemala in the Central Highlands, an area with remarkable biocultural diversity but alarming rates of poverty and malnutrition. In June-August 2014, 42 households were surveyed about their use of 74 crops either cultivated or harvested from the wild (hereafter, "crop diversity"), agrochemical use, and income generated from crop sales. We found that crop diversity was positively associated with dietary diversity, such that one additional food group was consumed within a household for each 5 crops added. On-farm income sources also diversified with crop diversity, where the average household sold approximately one-third of their total crop diversity. Specific types of heirloom and fruit crops (e.g., roctixl, macuy, ch'onte', guisquil, taro, chilacayote, pacaya palm, peach, plum, avocado, passionfruit) were especially likely to result in positive social and environmental outcomes. In contrast, other crops (e.g., export broccoli, cash crops) were more lucrative, but required expensive and potentially harmful agrochemicals. Importantly, the same practices associated with diet and income diversity (i.e., managing structurally

diverse polycultures and retaining forest remnants) are known to support birds of conservation concern in the same study area (Chapter 2). Thus, diverse agroecosystems may be better positioned to meet conservation and sustainable development targets than more intensive practices.

INTRODUCTION

In regions where forest habitats continue to be converted for human use, integrating conservation within activities that support sustainable livelihoods is imperative. This goal is especially challenging in areas where high levels of poverty and biodiversity co-occur, given the many inherent trade-offs. Since the 1960s, many "win-win" models have been proposed to alleviate poverty and conserve natural resources. Most famously, Norman Borlaug's, "Green Revolution," was intended to "feed a billion lives" using intensive and technologically-driven food cultivation while natural areas were kept separate for the environment (Waggoner 1996; Balmford et al. 2005, 2012; Borlaug 2007). While a "land sparing" approach that protects large areas of land from human activity can be highly effective (Wilson 1992; Edwards et al. 2010; Mahood et al. 2011; Leopold & Bell 2012), meeting human and non-human needs in working landscapes may require more integration, rather than separation, of forest and farmland (Greenberg et al. 1997; Green et al. 2005; Perfecto 2009; Bakermans et al. 2011; Kennedy et al. 2011; Pywell et al. 2012; McDermott & Rodewald 2014). Despite the natural alignment of strategies to conserve the environment and alleviate poverty, there has been a persistent undertone of antagonism between and among development and conservation in rural areas (Lee & Barrett 2000). Today, thinkers within international development have begun to shift towards a more integrated approach in which poverty alleviation is addressed within the context of the environment given that rural livelihood strategies are often dependent upon the natural resource base (Scoones 1998; Amekawa 2011; ICSU & ISSC 2015).

Tropical agroecosystems well illustrate the complexity of reconciling agricultural production with conservation, and many rural development programs attempt to tackle such challenges through the lens of sustainable rural livelihoods (Chambers & Conway 1992; Scoones 1998; Perfecto 2009; Amekawa 2011; Altieri & Toledo 2011). The "Sustainable Livelihoods" framework (SL) was one approach developed as a tool to understand the complexities of rural livelihoods while guiding development interventions that would alleviate poverty from multiple sectors (i.e. compared to single sector approaches based in agronomy or economics alone). Most commonly, a livelihood is defined using Chambers and Conway as: "the capabilities, assets (including both material and social resources) and activities for a means of living. A livelihood is sustainable when it can cope with and recover from stresses and shocks, maintain or enhance its capabilities and assets, while not undermining the natural resource base" (1992). More comprehensively, SL was expanded by Scoones (1998) to include five different capitals that could be diversified in development projects including: physical (e.g., infrastructure, tools, inputs), human (e.g., nutrition, education), natural (e.g., biodiversity, land, forests, water), social (e.g., networks, skills, knowledge), and financial (e.g., incomes, loans). Several case-studies have used the SL framework to address poverty alleviation and conservation within tropical fisheries (Allison & Horemans 2006) and cultivation of non-timber forest products within tropical forests (Chirwa et al. 2008), though the effectiveness of a sustainable livelihoods approach overall has mixed evidence. For example, while the Millennium Development Goals intended to "lift a billion lives out of poverty," it was arguably through a top-down approach that emphasized off-farm livelihoods, often at the expense of the environment (Sachs et al. 2009; Amekawa 2011). To address this shortcoming, Amekawa (2011) and Altieri and Toledo (2011) expanded the SL framework using an agroecological lens that emphasizes on-farm livelihoods (i.e. subsistence agriculture as a sustainable way of life). Likewise, Perfecto et al. (2009) suggest that agriculture, wildlife conservation, and food sovereignty must be explicitly linked. As such, sustainable

rural livelihood perspectives are moving towards socially-just and productive agroecosystems for humans and biodiversity.

One strategy that has the potential to dually support rural livelihoods and biodiversity is a landscape mosaic of diverse agroecosystems (i.e., polycultures) and integrated natural habitat remnants (Hausermann & Eakin 2008; Perfecto 2009; CIFOR 2011; Altieri & Toledo 2011; ICSU & ISSC 2015 - SDG #2.4). From an environmental perspective, polycultures can reduce soil erosion (up to 75%) on steeply farmed slopes in the Guatemalan highlands (Pope et al. 2015a). In addition, diverse agroecosystems can support high levels of planned (i.e. crop diversity) and associated (i.e. wildlife) agro-biodiversity (Conway 1987; Altieri 1995), especially when compared to monocultures (Beecher et al. 2002; Harvey & Villalobos 2007; Azhar et al. 2014). One of the best examples of a diverse agroecosystem is shade-coffee, which provides important habitat and food resources to Neotropical migratory birds (Greenberg et al. 1997; Perfecto et al. 2004; Bakermans et al. 2011; McDermott et al. 2015) that are often more abundant and diverse in coffee than natural forest (Petit et al. 1999; Bakermans et al. 2009). Similar benefits of structurally complex land-sharing systems (i.e. cacao, banana agroforestry) have been described for bats (Harvey and Villalobos 2007), ants (Vandermeer et al. 2008; Bisseleua et al. 2009), and plants (Egan & Mortensen 2012). Agrobiodiversity also sustains ecosystem services including pest control, seed dispersal, and soil aeration which benefits human communities.

A wide range of cultural, social, and economic benefits of diverse agroecosystems also flow to humans. For example, the tenets of managing diverse agroecosystems align especially well with social agrarian movements including food sovereignty (Martínez-Torres & Rosset 2010; Amekawa 2011; Altieri & Toledo 2011), which is defined by Pimbert (2009) as "the right of peoples to healthy and culturally appropriate food produced through ecologically sound and sustainable methods, and their right to define their own food and agriculture systems." Diverse food systems (e.g.,

agroforestry) can also yield higher incomes and return to labor as opposed to shifting cultivation (Rasul & Thapa 2006). In addition, more diversified cropping systems are presumed to better support nutrition, though there is surprisingly weak empirical evidence for this relationship. Whereas higher crop diversity is expected to facilitate more diverse diets, only a handful of studies have demonstrated this empirically (Ekesa et al. 2009; Powell 2012; Oyarzun et al. 2013; Jones et al. 2014; Herforth and Ahmed 2015; Sibhatu et al. 2015, but see Powell et al. 2015 for 6 of 12 studies that did not). Although case-studies from Malawi, Ecuador, Kenya, and Tanzania linked higher dietary diversity with greater crop diversity, especially in cases with female-led or wealthier households and when traditional heirloom varieties were integrated (Jones et al. 2014), empirical support in other areas of the world are needed.

Drawing on two components of the sustainable livelihoods framework, our research addressed empirical gaps by evaluating the consequences of certain agricultural practices to conservation and rural communities. Specifically, we examined the extent to which the diversity of crops cultivated or harvested supported diverse diets (i.e. human capital) and on-farm income streams (i.e. financial capital) for rural communities. Household dietary diversity is a widely accepted indicator of nutritional status (Hatløy et al. 2000; Arimond & Ruel 2004; Savy et al. 2005) and has been used to identify households and communities most at risk to further malnutrition (Swindale & Bilinsky 2006; Sibhatu et al. 2015). Diversifying on-farm income is known to be an effective strategy to alleviate poverty within smallholder farmers because a wider range of on-farm and income-generating practices can buffer against market shocks, unexpected famines, seasonal droughts, and climate change (Eakin 2005; Hausermann & Eakin 2008; Kasem & Thapa 2011). Based on our previous research and the published literature, we hypothesized that dietary diversity would rise with higher crop diversity, which included cultivated and harvested goods, because subsistence farmers generally eat what they grow (Jones et al. 2014). In addition, we hypothesized that the number of

crops sold to markets would increase with crop diversity as a wider selection of products would be available to sell. That said, we expected crops would vary in the degree to which they aligned with social and ecological outcomes, particularly regarding cash-crops and culturally significant heirloom varieties.

We focused on Mayan agroecosystems within the Highlands of Guatemala in Alta Verapaz, a region with remarkable biocultural diversity and alarming rates of poverty for rural communities (feedthefuture.org 2011; Birdlife International 2014). In addition, Q'eqchi' Mayan communities are facing some of the highest levels of malnutrition in the Western Hemisphere and primarily rely on subsistence agriculture on steep mountain slopes for a means of living (feedthefuture.org 2011). Deforestation of cloud forests continues at higher rates than previously described (3% per year, Pope et al. 2015b), thereby degrading soils, threatening biodiversity, and compromising the ability of Q'eqchi' Mayans to rely on forests for food and fiber subsistence. Despite human impacts, impressive levels of biodiversity persist, including >300 bird species, 20 of which are restricted-range endemics, and 3 high priority migratory species. Our previous work demonstrated that when managed to retain structural and floristic diversity, Mayan agroecosystems support birds of conservation concern (Chapter 2).

METHODS

Study Area

We studied agricultural food systems and practices within Q'eqchi' Mayan agroecosystems in the Central Highlands of Guatemala in the Department of Alta Verapaz, near the city of Cobán (15.4833° N, 90.3667° W). Our study area was located within two Sacred Mountain Ranges, the Yalijux and Sacranix, ancestral homelands to Q'eqchi' Mayans (Figure 3.1). The area is a biocultural hotspot in that it retains traditional customs and cultures, including ancient agricultural practices, and rich

biodiversity. The Yalijux and Sacranix Mountain Ranges are further recognized as Important Bird Areas (IBAs) by BirdLife International (GT010, GT070, Birdlife International 2015a, 2015b) and fall within the North Central American Endemic Bird Area (EBA #18 Birdlife International 2014). Rare cloud forest species including the Resplendent Quetzal (*Pharomachrus mocinno*), globally threatened Highland Guan (*Penelopina nigra*), Spotted Nightingale-thrush (*Catharus dryas*) among others live within forest fragments and are well known by local people by sight and sound. Our study area also was an important wintering location for many Neotropical migratory birds that spend half the year or longer on site including the endangered Golden-cheeked Warbler (*Setophaga chrysoparia*), Golden-winged Warbler (*Vermivora chrysoptera*), and Wood Thrush (*Hylocichla mustelina*). Birds have cultural significance as well, and many species have associated Q'eqchi' names and ethno-ornithological histories from multiple Mayan groups (Hull and Fergus 2011). The region has been heavily fragmented, and less than 3% of forests are protected (Bird Life International 2014). In addition to issues related to land tenure and rights, fuelwood extraction for cookstoves and slash-and-burn of secondary vegetation remain two important sources of continuing deforestation (Pope et al. 2015a).

Our study area included three remote villages located within a mosaic of agriculture, cloud forest, pine-oak forest, secondary forest, and pine plantations between 1100 and 2300 m elevation (Figure 3.1). Annual rainfall fluctuates between 3,000-4,000mm of rain not including lateral filtration from cloud forests (MAGA 2001). Soils were generally poor and highly erodible (Pope et al. 2015b), to the point where the Guatemalan Ministry of Agriculture has classified most highland soils as non-arable (MAGA 2001). Nevertheless, hundreds of mountain villages depend upon steep slopes of land for subsistence, even more so for Q'eqchi' Mayans who live at the highest elevations, compared to the other 22 Mayan groups, which causes additional strain on over-worked land. The governmental response has been to implement widespread chemical fertilizer subsidy programs to increase

production while local non-governmental programs which promote organic soil enrichments using agroecological techniques (i.e. agroforestry, organic fertilizers).

Although practices vary by village, Q'eqchi' Mayan agriculture is typically subsistence-based, and most farmers continue to use pre-Colombian "milpas" of corn, beans, and squash polycultures. Mayan agroecosystems are remarkably diverse in terms of the plants cultivated for foods and fibers. For example, over 10 distinct varieties of corn, and 10 varieties of beans are intercropped as a polyculture with heirloom squash, chili, as well as deciduous fruit trees including plum, peach, and avocado. Families consume multiple heirloom vegetables from home gardens as well as wild plants from cloud forests and the secondary "guamil," including micronutrient-rich leafy greens, Roctixl (*Cnidoscolus chayamansa*), and Macuy (*Solanum nigrescens*). Over the last decade, traditional agricultural approaches, such as organic fertilizers, terracing and inter-cropping, have been increasingly supplemented with use of agrochemicals. The popularity of cash-cropping has also grown so that it is now common to see crops like shaded coffee and cardamom cultivated in polycultures with bananas, pacaya palm, avocado, and taro. Likewise, relatively new export crops, such as broccoli, cabbage, and green beans, are often cultivated at higher elevations unsuitable for more traditional crops (i.e., banana, citrus) (Hamilton & Fischer 2005).

We selected for study three remote Q'eqchi' villages, Sebob, Sanimtaca, and Chichen, based on accessibility and proximity to a local NGO, Community Cloud Forest Conservation (CCFC), an organization dedicated to conservation using a grassroots development approach. Villages varied in elevation, land use practices, and socio-economic status and represented a diversity of ecological, agricultural and social gradients. Sebob is the most remote and highest-elevation village (1800-2300-m), where fruit trees and export vegetables are cultivated instead of typical cash-crops including coffee and cardamom (Figure 3.2a). Ecologically, it was the steepest and most deforested due to slash-and-burn agriculture and fuelwood extraction for sale and subsistence. Work and educational

opportunities seemed the most limited in Sebob among all villages, likely due to its remoteness. In contrast, Sanimtaca was the lowest elevation village (1100-1500-m) and the only with a cooperative managed by community members for both coffee and cardamom (Figure 3.2b). Large polyculture farms were common, usually with high diversity of shade trees and an assortment of heirloom vegetable gardens, fruit trees, coffee, cardamom, and pine plantations where farmers were subsidized by the government to grow pine for sale in domestic or international markets (PINFOR – Programa de Incentivos Forestales). Other livelihood opportunities such as weaving, and off-farm labor in adjacent cooperatives were common, though education past primary school is still a barrier. Sanimtaca also managed a small cloud forest reserve and avi-tourism program, though tourism was infrequent. Chichen was closest to our partnering NGO, Community Cloud Forest Conservation (CCFC), and was the only village with electricity and direct access to buses on paved roads. Farm size was the smallest in Chichen as its land was part of a large German farm before being returned to Q'eqchi' families, in part, as small parcels after the Civil War in return for labor on nearby coffee plantations. Small-scale vegetable production interspersed with diverse fruit trees was most common, and livestock including pigs and cows were raised for sale in markets. Access to schools and markets was less challenging, though it was similar to Sebob in that few livelihood opportunities were available.

Household Surveys

Household surveys were completed using a two person field team from June-August of 2014 by the first author and a local Q'eqchi' Mayan college student, who was bilingual in Spanish and Q'eqchi Mayan and an employee of CCFC. In total, 42 Q'eqchi' households were surveyed in the three villages, where questionnaires were conducted in the primary language of the area, Q'eqchi' Maya. Households were selected based on close proximity to bird monitoring locations from our

complementary research (Chapter 2). In all cases, an adult (>18 years old), usually the head of household, gave verbal consent to participate in the survey consistent with our Institutional Review Board protocol. We assessed the diversity of foods and fibers cultivated by the household by asking 12 questions regarding crops eaten and/or sold, and each crop's average market price, average income during the last growing season, and agrochemical use (e.g., fertilizer, herbicide, insecticide, and fungicide). See example questionnaire in Appendix E. For the purposes of this study, we define "crop diversity" as all cultivated crops, livestock, as well as wild harvested foods and fibers. We initially focused on 50 products, including vegetables, fruits, wild harvested foods and fibers, livestock, and "other" goods such as coffee or cardamom known to grow in the region (T Cahill 2014, pers. comm., 30 June 2014). However, if any foods or fibers were used by a household and not on our list, we added them to the master list in Q'eqchi', Spanish, and English and included them in subsequent surveys for a total of 74 crops (Appendix F).

Data Analysis

We measured the Household Dietary Diversity Score (HDDS) for each household which is a metric of the number of different food groups consumed over a given reference period (Swindale & Bilinsky 2006). This metric has been widely used to estimate household-level food security and serves a proxy indicator for household *access* to food (Hoddinott & Yohannes 2002). Several studies have also linked HDDS to several positive social outcomes, including improved nutrient intake (Savy et al. 2005), child anthropometric status (Arimond & Ruel 2004), and socio-economic status (Hatløy et al. 2000). We prepared and used a list of foods that participants indicated they consumed at home over the last growing season to estimate dietary diversity, excluding fibers and other food crops that were not consumed. Because many foods were seasonally consumed, we felt the growing season timeframe would better reflect dietary diversity than selection of an arbitrary and short period (e.g.,

24 hours or 7 days) as used within other studies (Ekesa et al. 2009; Jones et al. 2014). Each consumed crop cultivated or harvested was categorized into one of 15 food groups described by the Food and Agriculture Organization (FAO 2011) (Appendix F, Table 3.1). To calculate a "Simple HDDS," we summed the number of food groups that were consumed by the household, with each food group counting towards the final score. For example, if a household consumed bananas, food group "F" would get a score of "1" and the same process was followed for all subsequent food groups for a total score of 11, as 4 food groups were more commonly purchased in markets and not explicitly asked for (eggs, fish, milk and oils). A second score was also calculated, the "Vitamin A Weighted HDDS," because Vitamin A continues to be a significant micronutrient deficiency in the region (feedthefuture.org 2011). In this case, we tallied across individual food items that were rich in Vitamin A (e.g., specific fruits, vegetables, leafy greens) as well as the FAO food categories to differentiate between households that were consuming little to no Vitamin A rich foods compared to those with more variety. Thus, a score of "1" was assigned for each type of Vitamin A rich food consumed out of 13 varieties, though the maximum number a household consumed was eight. This left a total possible score of 16. The equations below were used to calculate both scores for each household where each letter indicates a food category (Table 3.1), scores were then averaged by village.

Simple HDDS = A + B + C + D + E + F + G + H + K + N + O *(max =11)*

Vit. A Weighted HDDS = A + C + E + G + H + K + N + O + Σ All Vit. A rich foods *(max = 16)*

To test the hypothesis that crop diversity was positively associated with dietary diversity, we used a simple linear-regression model between the two which was generated in program R (R Core Team 2013). We also assessed the relationship between crop diversity and the number of crops sold

in markets using the same approach to test our hypothesis that farmers with higher crop diversity indicated they also sold more types of crops.

Descriptive statistics by village were calculated, including farm size, average crop diversity, dietary diversity, the number of crops consumed and sold, and agrochemical use. Differences among the three study sites were tested using a One-Way ANOVA and an alpha level of <0.05 to indicate significance and post-hoc comparisons were made using a Tukey Pairwise Comparison test (Table 3.2). Land use composition of cloud forest, mixed forest and agriculture also was measured using existing land use maps (Pope et al. 2015b) of each village by calculating raster areas in ArcMap 10.1 based on the land use class.

Income generated per crop was averaged across all households that sold each crop, and then standardized by one work-day equivalent of 50 quetzales (about $7). First, the average price per unit sold was calculated for households with sufficient data, then the average price was multiplied by the total number of units sold per household during the last growing season. In the few instances where households reported different units of measurement for sale in markets (i.e. a box versus a pound), we eliminated the least common unit reported for final calculations.

RESULTS

Household Characteristics

In total, 32 women and 10 men between the ages of 18 and 90 participated in surveys. Q'eqchi' Maya was the primary language spoken by all, with a few individuals also able to speak Spanish. Farm size varied among villages (Table 3.2) with a minimum of 0.04 hectares (ha) and a maximum of 8.00 ha, though the smallest farms were found in Chichen (0.325 ± 0.084 SE) and largest in Sebob (2.076 ±0.544). Most houses were constructed with wooden boards, tin roofs, dirt floors, open cooking stoves with limited ventilation, and a lack of electricity or potable water. A few

exceptions were found in Sanimtaca and Chichen, where several families had efficient cookstoves, Ecofilters for fresh water, solar lights, and sometimes concrete floors or walls. Elders tended to retain traditional thatch roofs made out of a wild grass, Quim ha (*Imperata contracta*) or sometimes sugar cane leaves. We did not explicitly ask level of education of the head of household, but most adults have only completed between third and fifth grade, usually lower for women. In rare cases, male children are sent to middle school to complete ninth grade, but cost (Q1000 per year) and remoteness are serious barriers for rural families. Barriers for young women are even greater, and seldom did girls attend school past fifth grade.

Crop Diversity

Households used a total of 74 crops including 27 fruits, 24 vegetables, 13 wild cultivated goods (i.e. forest), seven livestock, and three "other" (Table 3.3). The average village crop diversity was 25 ± 5 SD for Sebob, 24 ± 6 for Chichen, and 31 ± 7 for Sanimtaca (Table 3.2) of which approximately 12 crops were vegetables, six fruit, six wild-cultivated goods, two livestock and two other. Of the total crops cultivated, 85% of were eaten or used in the home (i.e. food or fiber), and 32% were sold in markets, while many crops were both eaten and sold. Prevalence of each crop type varied widely among households (Table 3.3).

Most households cultivated the following crops: maize (n=42 households), heirloom beans (n=37), peaches (n=40), banana (n=29) and guisquil squash (n=42). These crops were generally grown together in a traditional "milpa," or collected from the cloud forest understory such as the iron and Vitamin-A rich roctixl (n=34) and macuy (n=38). Every household indicated that fuelwood was used for subsistence. There were 41 food crops cultivated by at least five households and sold to markets at varying levels (Table 3.4). The most commonly sold crops were coffee (n=22), cardamom (n=15) as well as traditional subsistence crops including banana (n=22) avocado (n=19), heirloom

beans (n=19), and guisquil squash (n=18). Although export crops such as broccoli, green beans, coffee and cardamom were primarily grown for sale, they also were regularly consumed among households providing the benefits of a "multi-use" crop. Broccoli, green beans, and foreign tomato, were crops sold at moderate levels (n = 10, 17, and 23 respectively), each recently introduced to the region from Mexican vegetable companies and US agricultural development efforts with the intent to boost household incomes.

Household Dietary Diversity

Crop diversity was positively associated both with Simple HDDS (β= 0.065 ± 0.020 SE; $F_{1,40}$ = 10.9, P = 0.002) and Vitamin A HDDS (β= 0.020 ± 0.027 SE; $F1_{,40}$ = 57.48, P = <0.001), indicating that households generally consumed what they grew (Table 3.2, Figure 3.3). Communities significantly differed in the diversity of diets (Table 3.2) where the Simple HDDS was highest in Sanimtaca (10.1 ± 0.66 SD) and lowest in Chichen (9.2 ± 0.92). Similarly, the Vitamin A HDDS ranged from 12.0 (± 1.63) in Chichen to 13.76 (± 1.39) in Sanimtaca (Table 3.2). Every household consumed at least one vitamin A rich vegetable and leafy green, though only 25% of households consumed vitamin A-rich fruits (e.g., mango, papaya or passionfruit) (Table 3.5). Chicken was the main animal protein reported by 100% of households. We did not assess consumption of eggs (category I), fish/seafood (category J), milk products (category L), or oils/fats (category M) as we were only interested in foods cultivated or harvested on farm and in natural areas. Anecdotally, eggs and milk seemed infrequently consumed in part because cows were usually raised for sale in markets.

Crop Market Prices and Income Diversity

Crop diversity was positively related to the number of crops sold in markets (β = 0.474 ±0.106 SE; $F_{1,39}$ = 19.98, P <0.001), where households with higher crop diversity had a wider range of crops

they sold (i.e. higher on-farm income diversity) (Table 3.2). Average market price and income generation over a growing season varied widely among crops (Figure 3.4). The most lucrative crops per season were generally export crops, though maize was the fourth most lucrative crop sold to markets which provided an average income equal to 60 work-days, and at a selling price similar to cardamom. Fast-growing broccoli generated the highest income of Q8,104.00, or 162 work-days (Table 3.6) at a price of less than Q1.00 per pound. However, because farmers generally required micro-loans to pay for seeds and agrochemicals, the net income generated must be substantially lower than market prices reflect. Similar inputs are associated with other export vegetables, such as green beans with its average income of Q4,920.00 or 98 work-days at an average price of Q270.00 per quintal (100 pounds). Coffee and cardamom also were important income generators for Sanimtaca, where coffee cooperatives keep selling prices high (Q173 and Q134 per quintal respectively). Important to note, coffee rust (i.e. roya) has negatively affected coffee and cardamom growers in the region likely depressing prices relative to the last several years. Multi-use crops including plum, pacaya palm, and chilacayote (an heirloom squash) were valuable for sale and nutrition, while requiring little to no agrochemical inputs. Price per unit for pacaya palm and chilacayote was generally high (Q8.75 and Q6.87), though overall income per season was significantly less than export crops. Although plums were sold at a higher price per unit than broccoli (Q1.33/pound), they generated less income because fewer units were sold. However, non-profit practitioners in the area report that some farmers make up to $1,500 USD from plums in one growing season (Rob Cahill pers. comm).

Agrochemical Use

The extent to which fertilizers, herbicides, fungicides, and insecticides were used varied widely among crops. Low-input crops included 9 different fruit trees, 2 heirloom vegetables, and

several wild plants harvested from the forest (Figure 3.5). In contrast, most crops within the milpa, including corn, beans, guisquil, chili, guisantes, and carrot, received moderate to high amounts of agrochemicals including 80% of households that used fertilizers on corn and beans, and varying levels of other agrochemicals. Four types of agrochemicals were heavily applied to export crops, especially broccoli, green beans, tomato, and coffee. Proportionally, broccoli had the highest agrochemical use, with 90% of those cultivating broccoli using fertilizer, fungicide, and pesticide, and 60% using herbicide (Table 3.7). The high use of agrochemicals largely reflects requirements by export vegetable companies, government subsidies, and also the prevalence of coffee rust in the region. In fact, all households used at least one type of agrochemical – all used fertilizers, 31 fungicides, 32 insecticides, and 27 herbicides.

DISCUSSION

Many development plans promote conservation and sustainable livelihoods through management of diverse agroecosystems and preservation of remaining forest (Perfecto 2009; Amekawa 2011; Altieri & Toledo 2011). Our research provides empirical support for this approach by showing that rural households have more diverse diets and on-farm incomes when a rich assortment of foods are cultivated and/or harvested from natural habitats. Our complementary work in this same system also indicates that diverse polycultures with forest remnants can support many bird species of conservation concern (Chapter 2). Thus, diverse agroecosystems may be better positioned to meet conservation and sustainable development targets than more intensive practices.

One of the most important findings of this study was that crop diversity was positively related to dietary diversity, a well-known indicator of nutritional status (Hatløy et al. 2000; Arimond & Ruel 2004; Savy et al. 2005). We showed that for every five additional crops cultivated or collected per household, one additional food group was consumed (Figure 3.3). High crop diversity may be a

cultural relict of traditional agricultural practices, as Mayan agroecosystems are known to be some of the most diverse food systems ever documented from both historical and contemporary views (Demarest 2004; Bohn et al. 2014). As most of the world's undernourished communities are comprised of smallholder farmers, diversifying production at the farm-level has been regarded as an important strategy to improve dietary diversity and quality (Remans et al. 2011; Jones et al. 2014; Powell et al. 2015). Despite the inherent diversity of many subsistence-based food systems, much of agricultural research and policy has focused on only a few staple crops including corn, rice, and wheat (FAO et al. 2015). The switch from diversified cropping systems to simple or cereal based ones has been implicated as a contributor to poorer diets in developing and developed countries, higher malnutrition, and loss of traditional knowledge (LaDuke 2006; Isakson 2009). Recent research confirms what many agrarian communities have known for millennia – diverse agroecosystems can improve human well-being. Thus, there is a great need for policies and programs to expand to include a wider diversity of crops (Altieri 2000; Jones et al. 2014).

Aligning with our hypothesis, as crop diversity increased, so did on-farm income diversity, which can promote resiliency within agroecosystems (Altieri 2000; Perfecto 2009; Amekawa 2011). We showed that the average household sold approximately one-third of their total crop diversity where households with higher crop diversity sold more types of products in markets including both export and subsistence-based (Table 3.2). Diversifying on-farm livelihoods can buffer against shocks from markets, unexpected famines, seasonal droughts, and climate change (Eakin 2005; Hausermann & Eakin 2008). Farmers who depend upon only a handful of export crops for income may be more at risk to external shocks especially without backing from cooperatives or certification agreements (Rettberg 2010). Moreover, several studies show that farmers intentionally participate in both market and subsistence agriculture because it provides a safety net (Barrett 2008). Critics argue that development frameworks including SL have focused too strongly on off-farm livelihood

diversification without recognizing the ability of subsistence farming itself to contribute to economic, natural and social capitals, and more generally, that it is a chosen way of life (Amekawa 2011). As such, social agrarian movements such as "La Via Campesina," the "agroecological revolution of Latin America," and food sovereignty call for the repeasantization of land in which communities can govern their own sustainable development within diverse agroecosystems (Perfecto 2009; Martínez-Torres & Rosset 2010; Altieri & Toledo 2011).

Our study suggests that specific types of heirloom and fruit crops (e.g., roctixl, macuy, ch'onte', guisquil, taro, chilacayote, pacaya palm, peach, plum, avocado, passionfruit) are especially likely to result in positive social and environmental outcomes. Although many of these crops fetch comparatively low income from markets, they are micronutrient rich, easily grown without agrochemical inputs, and are characteristic of sovereign food systems (Altieri & Toledo 2011; Chappell et al. 2013). Wild-harvested and heirloom varieties, in particular, have important health benefits medicinally, nutritionally, and spiritually (Baumflek et al. 2010; Kassam et al. 2010; Ruelle 2015), though they are often neglected within development programs (Ekesa et al. 2009; Martínez-Torres & Rosset 2010; Altieri & Toledo 2011). That said, recent programs have advocated for fruit trees as sustainable alternatives to improve nutrition and income (Akinnifesi et al. 2006; Jama et al. 2008). In addition, crops that do not use agrochemicals are less likely to create dependency upon external subsidies, pollute watersheds, erode soils, or negatively impact avian pollinators (Krebs et al. 1999; Potts et al. 2010; Hunke et al. 2015).

We suggest that other crops may have greater tradeoffs between benefits to people and the environment. New export crops such as broccoli, snow peas, coffee and cardamom generated a higher income compared to smaller-scale or subsistence crops, but they usually depend upon high agrochemical and labor inputs that may be less aligned with food sovereignty or the environment (Altieri 2009; Martínez-Torres & Rosset 2010). For example, in the Guatemalan region of Kaqchikel,

farmers accumulated debt from growing broccoli because the prices promised by vegetable companies were not realized (Hamilton and Fischer 2005). The motivation behind connecting peasant farmers to external markets often is to supplement incomes though crop sales so that food can be purchased in domestic markets (Lee & Barrett 2000; Jones et al. 2014). However, a division in the economic field calls attention to the unintended consequences of integrating smallholders into markets, including a potential decrease in crop diversity (Dewey 1989; Srinivasan et al. 2010), the risk of fluctuating exchange rates, and more rigorous food safety standards (Gómez et al. 2011). Yet, export vegetables may be one of the only convenient ways that smallholders with limited resources and access to land can generate income (Hamilton & Fischer 2005). Additionally, intensive cultivation may threaten food sovereignty by reducing soil health (Hunke et al. 2015) and preventing volunteer crops (i.e. beans that climb corn stalks) from growing due to overuse of herbicide, thus a potential decrease in crop yield and diversity are both concerns (Altieri 2009; Isakson 2009; Martínez-Torres & Rosset 2010; Pope et al. 2015a). Additional research examining farmers' choice to participate in broccoli cultivation, using principles of behavioral economics, may help to determine household-level trade-offs. When grown in a way that is complementary, not exclusionary, to traditional food systems, export crops can have positive financial and ecological outcomes as shown through cultivation of shaded coffee, cardamom, and cacao in Latin America (Perfecto et al. 1996; Greenberg et al. 2000; Hausermann & Eakin 2008), though external shocks including diseases and unstable market prices should always be considered.

Overall, our work provides evidence that a diverse matrix with farmland and natural forest can provide measurable benefits to human and bird communities – a pattern also shown by others (Luck & Daily 2003; Perfecto 2009; Altieri & Toledo 2011; Kennedy et al. 2011). In our complementary research (Chapter 2), the same diverse agroecosystems that supported farmers also provided habitat features used by several bird species (e.g., tree cover, diverse plants). Compared to monocultures,

polycultures were more structurally and floristically diverse with higher canopy cover, tree density, and presence of epiphytes – all of which promoted bird conservation (Chapter 2). Indeed, many studies report that these and other features associated with agroforestry, such as foliage cover, size and diversity of trees, support resident and migratory birds (Perfecto et al. 1996; Greenberg et al. 1997, 2000; Beecher et al. 2002; Bakermans et al. 2011; McDermott et al. 2015). Habitats that are beneficial to birds are also valuable to people because trees and other plants promote watershed management and erosion control (Udawatta et al. 2010; Supriyadi 2014; Pope et al. 2015a) in addition to the diet and income benefits reported in our research and elsewhere (Amekawa 2011; Altieri & Toledo 2011; Jones et al. 2014).

Our study highlights the potential contribution of forests to sustainable livelihoods and conservation alike. On the human side, every household collected and used items from forest remnants, and forests were good sources of vitamin A and iron rich foods. On the conservation side, the amount of cloud forest within a 100 hectare landscape predicted occurrence of several forest specialist and endemic species (Chapter 2). A diverse agricultural matrix with forest fragments also facilitates avian movements and promotes colonization and population persistence (Bierregaard et al. 1992; Vandermeer & Carvajal 2001; Graham et al. 2002; Luck & Daily 2003; Perfecto 2009; Kennedy et al. 2011). Maintaining cloud forest fragments from further deforestation will help ensure ecosystem services and critical habitat remains for specialist species, as well as the nutritious and culturally significant foods and fibers typically harvested within natural areas (Baumflek et al. 2010; Chandler et al. 2013). Interestingly, recent research within our same study area suggests that improving soil health on agricultural land is likely to be a central component to cloud forest conservation because healthier soils would reduce dependency upon slash-and-burn practices, a main driver to deforestation (Pope et al. 2015b). As such, a diverse agricultural matrix is just as important as forests to sustainable development and biodiversity conservation.

Several caveats to our research are important to note. Most importantly, our dietary diversity scores may be underestimates because they did not reflect consumption of foods purchased off-farm, as is typically done in other studies (Ekesa et al. 2009; Jones et al. 2014; Sibhatu et al. 2015). In addition, we did not consider the wide range of factors that can affect dietary diversity, including gender, power, education, wealth, social capital, among others (Jones et al. 2014; Herforth & Ahmed 2015). Moreover, we recognize that, although dietary diversity is a common proxy for nutritional status (Hatløy et al. 2000; Arimond & Ruel 2004; Savy et al. 2005; Swindale & Bilinsky 2006) it only captures the presence, but not the frequency or quantity, of foods consumed. Our study also is limited in that we could not relate total on-farm income (summed by number of crops sold) to crop diversity because we lacked two pieces of information. One, we did not measure the net income generated by each crop because we did not have data that included costs of agrochemicals, tools, or hired labor required. Second, we did not collect information about off-farm income streams which are known to be associated with crop diversity (Jones et al. 2014). Rather, we showed that households with higher crop diversity have a wider range of products they are able to sell (i.e. greater on-farm income diversity).

Despite those caveats, our study suggests that diverse agroecosystems and cloud forest fragments support human communities by way of promoting diverse diets and income streams. That fact, coupled with our previous research on bird communities, suggests that management of diverse agroecosystems may support development and conservation goals within biodiverse regions struggling with poverty and malnutrition. To ensure a sustainable future for highland biodiversity (particularly in tropical cloud forest ecosystems) and rural development, agricultural interventions should align with conservation goals and community needs, and be supported empirically. Future research should address the appropriateness of current development projects in the region, specifically regarding external market integration (i.e. broccoli) and a potential over emphasis on

staple crop yields. Agroecologically-motivated development strategies that integrate export crops within traditional food systems and focus on a larger diversity of crops may be better suited. This evidence-based approach worked well in our focal communities, and we worked closely with collaborators to reintroduce heirloom crops, plant fruit trees, and engage stakeholders in participatory discussions about conservation and development within the greater Highlands (Chapter 1). Overall, identifying and advocating for biodiversity-friendly agroecosystems is likely to contribute to bird conservation and sustainable livelihoods in Guatemala especially if put into the context of sovereign food systems.

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Table 3.1: Household dietary diversity food groups used for dietary diversity calculations. Vitamin A rich vegetables, leafy greens, and fruits are emphasized in categories B, D, and F.

Household dietary diversity food group	Code	Description
Cereals	A	Bread, rice noodles, biscuits, cookies, or any other foods made from millet, sorghum, maize, rice, wheat, or other locally available grain
Roots and tubers	C	White potatoes, white yams, manioc, cassava or any other foods made from roots or tubers
Vegetables: other	E	Any local Guatemalan vegetable
Fruits: other	G	Any local Guatemalan fruit
Meats, poultry, offal	H	Beef, pork, lamb, goat, rabbit wild game, chicken, duck, or other birds, liver, kidney, heart, or other organ meats
Eggs*	I	Any Eggs
Fish and seafood*	J	Fresh or dried fish or shellfish
Pulses/legumes/nuts	K	Foods made from beans, peas, or lentils
Milk and milk products*	L	Cheese, yogurt, milk or other milk products
Oils/fats*	M	Foods made with oil, fat, or butter
Sugar/honey	N	Any sugar or honey
Miscellaneous	O	Any other foods, such as condiments, coffee, tea
Vit. A rich		
Vegetables: yellow/orange	B	Pumpkin, carrots, squash, or sweet potatoes that are yellow or orange inside
Vegetables: dark leafy greens	D	Dark, green, leafy vegetables such as cassava leaves, bean leaves, kale, spinach, pepper leaves, taro leaves, and amaranth leaves
Fruits: yellow/orange	F	Ripe mangoes, ripe papayas or other locally available Vit. A rich fruit

*Indicates a food group that was not surveyed for because the food group was not primarily cultivated or harvested on-farm.

Table 3.2: Comparison of 3 villages in the Department of Alta Verapaz, Guatemala by farm size, crop diversity, dietary diversity, number of crops consumed and sold, and number of crops using agrochemicals. Land use composition of primary forest, secondary/mixed forest, and agriculture is described proportionally

Characteristic	Chichen	Sanimtaca	Sebob	F-statistic (df = 2, 39)
Average:				
Farm size (ha)	0.32 (0.08)	1.96 (1.95)	2.08 (0.54)	
Crop Diversity***	24 $(4.11)_a$	31.42 $(5.23)_b$	24.67 $(5.19)_a$	8.94
Simple HDDS*	9.2 $(0.92)_a$	10.1 $(0.66)_b$	9.5 $(5.19)_a$	3.75
Vit. A Weighted HDDS**	12 $(1.63)_a$	13.76 $(1.39)_b$	12.27 $(1.49)_{ab}$	7.12
Number of Crops				
consumed**	21.3 $(3.7)_{ab}$	26.01 $(5.8)_b$	20.8 (4.7)a	5.29
sold in markets	6.8 (4.2)	11.53 (8.9)	8.6 (5.5)	
Percentage of Crops:				
using fertilizer	20.36% (11.0)	15.70% (6.7)	13.60% (7.7)	
using herbicide*	6.80% $(9.8)_{ab}$	7.24% $(5.1)_b$	3.45% (4.2)a	3.59
using fungicide*	8.64% $(9.5)_{ab}$	8.42% $(9.5)_b$	2.76% (4.4)a	5.77
using insecticide*	8.58% $(10.1)_{ab}$	8.21% $(5.3)_b$	2.76% (4.4)a	5.13
Land Use Composition (%)				
primary cloud forest	20%	37%	15%	
secondary/mixed forest	29%	10%	15%	
Agriculture	50%	53%	71%	

*p-value <0.05 **p-value <0.01 ***p-value <0.001 (ANOVA).

$X_{a,b,c}$ indicates Tukey Pairwise Comparison where subscripts designate significantly different groups

Table 3.3: Prevalence of 74 fruits, vegetables, wild harvested foods and fibers, livestock, and other crops used from 42 Q'eqchi' Mayan households in the Department of Alta Verapaz, Guatemala, 2014-2015.

Fruits (n=27)	Prevalence (# of households)	Vegetables (n=24)	Prevalence	Wild harvested (n=13)	Prevalence	Livestock (n=7)	Prevalence	Other (n=3)	Prevalence
Peach	40	Guisquil squash	42	Fuelwood	42	Chicken	42	Pine tree	39
Avocado	32	Corn	42	Tzoloj	39	Pig	13	Coffee	26
Pacaya	31	Taro	40	Macuy	38	Turkey	11	Cardamom	17
Banana	29	Herbs	39	Flowers	36	Cow	7		
Orange	23	Hojas de Mosh	39	Roctixl	34	Duck	2		
Plum	15	Beans	37	Chonte	15	Goat	1		
Pineapple	13	Chili	27	Quim ha	15	Sheep	1		
Coyou	12	Chilacayote	27	Tree Fern	15				
Guyaba	12	Sugar Cane	26	Wild animal	4				
Passionfruit	9	Ayote	25	Tzaaj	3				
Injerto	4	Foreign Tomato	23	Achiote	1				
Lemon	3	Onion	18	Chipilin	1				
Macademia	3	Green beans	17	Tzuk	1				
Mandarine	2	Camote	13						
Raxtul	2	Rabano	13						
Albahaca/Basil	1	Arakacha	12						
Chilga	1	Guisantes	12						
Guic	1	Tomato	12						
Lime	1	Yucca	12						
Mango	1	Broccoli	10						
Nance	1	Carrot	5						
Palal	1	Beet	4						
Papaya	1	Tzumuy	3						
Pear	1	Arbejas	1						
Pericon	1								
Quib	1								
Romero	1								

Table 3.4: Common food crops consumed and sold in markets in order of most to least prevalent in diet from 42 Q'eqchi' Mayan households in the Department of Alta Verapaz, Guatemala

		No. of Households				No. of Households	
Crop name	Type	Consume	Sell	Crop name	Type	Consume	Sell
Corn	Vegetable	42	8	Orange	Fruit	23	2
Guisquil squash	Vegetable	42	18	Onion	Vegetable	18	3
Chicken	Livestock	42	16	Green beans	Vegetable	17	12
Herbs	Vegetable	39	17	Chonte	Wild - Vegetable	15	1
Hojas de Mosh	Vegetable	39	18	Plum	Fruit	14	11
Taro	Vegetable	39	13	Pineapple	Fruit	13	2
Peach	Fruit	39	5	Camote	Vegetable	12	2
Beans	Vegetable	37	19	Guisantes	Vegetable	12	3
Macuy	Wild - Vegetable	37	6	Rabano	Vegetable	12	5
Tzoloj	Wild - Vegetable	37	2	Tomato	Vegetable	12	6
Roctixl	Wild - Vegetable	32	1	Yucca	Vegetable	12	2
Avocado	Fruit	31	19	Coyou	Fruit	12	3
Pacaya	Fruit	31	16	Guyaba	Fruit	12	0
Banana	Fruit	29	22	Arakacha	Vegetable	11	1
Chili	Vegetable	27	9	Broccoli	Vegetable	10	8
Chilacayote	Vegetable	26	8	Turkey	Livestock	10	3
Coffee	Other	26	22	Passionfruit	Fruit	8	1
Pine tree*	Other	26	13	Carrot	Vegetable	5	3
Ayote	Vegetable	25	5	Pig	Livestock	5	13
Sugar Cane	Vegetable	25	7	Cardamom	Other	3	15
Foreign Tomato	Vegetable	23	10				

***Pine is the only non-food crop included and is used not consumed.

Table 3.5: Average (SD) number of crops eaten per food group by village and the total percentage of households eating each food group in the Department of Alta Verapaz, Guatemala. Note low percentage eating Vitamin A rich fruits.

		AVERAGE # CROPS CONSUMED						% CONSUMING
Code	FAO Food Group	Chichen		Sanimtaca		Sebob		All Households
A	Cereals	1.0	(0.0)	1.0	(0.0)	1.0	(0.0)	100%
B	Vitamin A rich vegetables and tubers	2.4	(0.7)	2.1	(0.8)	2.0	(0.9)	100%
C	White roots and tubers	1.3	(0.7)	1.8	(0.9)	1.3	(0.5)	95%
D	Vitamin A rich dark leafy greens	2.4	(1.1)	3.6	(0.6)	2.9	(0.6)	100%
E	Other vegetables	3.4	(2.0)	5.0	(2.0)	4.6	(2.1)	100%
F	Vitamin A rich fruits	0.1	(0.3)	0.3	(0.4)	0.3	(0.5)	24%
G	Other fruits	4.8	(0.9)	5.8	(2.0)	3.6	(0.7)	100%
H	Flesh meat	1.2	(0.6)	1.4	(0.7)	1.6	(0.9)	100%
I	Eggs	--	--	--	--	--	--	--
J	Fish and seafood	--	--	--	--	--	--	--
K	Legumes, nuts, and seeds	0.9	(0.3)	1.1	(0.4)	0.9	(0.4)	90%
L	Milk and milk products	--	--	--	--	--	--	--
M	Oils/fats	--	--	--	--	--	--	--
N	Sugar/honey	0.3	(0.5)	0.9	(0.3)	0.5	(0.5)	60%
O	Spices, condiments, and beverages	2.7	(0.9)	2.9	(0.7)	2.0	(0.6)	98%

Table 3.6: Market price and income generated per growing season for 25 commonly sold crops in the Department of Alta Verapaz, Guatemala 2014-2015. Crops are ordered by highest income generated and work day equivalent assumes 50.00 quetzales/day where Q1.00= $7.75. Sample size is the number of households with sufficient data to calculate prices and income. *Crops with price data only.

			MARKET PRICE/UNIT (Q)		INCOME/SEASON (Q)					
Crop	Use	Unit Sold	Mean	SE	Mean	SE	Work Day Equivalent	SE	Average No. units Sold	Sample Size
Broccoli	Export	1 pound	0.98	0.03	8,104.29	3793.75	162.09	75.88	7,914.29	6
Green Beans	Export	100 pounds	270.83	33.18	4,920.00	1973.82	98.40	39.48	21.00	6
Coffee	Export	100 pounds	174.33	16.63	3,228.98	1253.93	64.58	25.08	15.23	15
Corn	Subsistence	100 pounds	136.07	4.56	3,083.00	1498.56	61.66	29.97	22.20	7
Cardamom	Export	100 pounds	133.50	35.59	1,680.83	1539.14	33.62	30.78	13.86	13
Plum	Multi-use	1 pound	1.33	0.15	841.67	242.97	16.83	4.86	652.08	12
Beans	Subsistence	1 pound	3.48	0.16	762.79	244.53	15.26	4.89	228.36	20
Pacaya	Multi-use	1 dozen	8.75	0.76	762.25	544.35	15.25	10.89	69.29	14
Chicken	Subsistence	Single	70.42	9.21	698.75	152.96	13.98	3.06	8.75	11
Avocado	Multi-use	Single	1.16	0.18	461.79	116.43	9.24	2.33	327.14	16
Chilacayote	Multi-use	Single	6.67	1.54	213.00	59.82	4.26	1.20	124.17	6
Foreign Tomato	Export	Single	0.97	0.16	205.00	125.65	4.10	2.51	141.73	8
Herbs/Cilantro	Multi-use	1 bunch	1.24	0.19	166.88	72.28	3.34	1.45	133.69	16
Banana	Multi-use	Single	0.56	0.07	90.42	46.92	1.81	0.94	147.92	18
Sugar cane	Multi-use	1 cart	14.50	2.92	75.00	16.27	1.50	0.33	8.75	6
Peach	Subsistence	Single	0.38	0.11	66.25	18.56	1.33	.37	160.83	5
Chili	Multi-use	Single	0.44	0.04	47.50	11.83	<1	.24	112.14	5
Guisquil squash	Multi-use	1 bunch	1.18	0.09	42.00	12.72	<1	.25	38.69	16
Taro	Multi-use	Single	0.75	0.07	27.64	5.17	<1	.10	35.96	13
Hojas de mosh	Multi-use	1 bunch	1.01	0.09	26.95	6.04	<1	.12	25.93	17
Flowers	Market	1 bunch	0.98	0.35	25.54	15.57	<1	.31	18.17	10
Macuy	Subsistence	1 bunch	1.00	0.16	23.88	9.95	<1	.20	20.25	5
Pig*	Market	Single	950.00	160.73	NA	NA	NA	NA	NA	6
Pine*	Export	Single	300.00	100.00	NA	NA	NA	NA	NA	3
Cow*	Market	Single	3500.00	232.38	NA	NA	NA	NA	NA	5

Table 3.7: Agrochemical use with 34 common food crops in order of highest to lowest proportion of households using agrochemicals in the Department of Alta Verapaz, Guatemala 2014-2015. The number of chemicals 0-4 represents use of fertilizer, herbicide, fungicide, and/or pesticide, or zero total use

Name	Use	Total Prevalence	% HH using chemicals	Fertilizer Use	Herbicide Use	Fungicide Use	Pesticide Use	No. chemicals
Broccoli	Export	10	83%	9	6	9	9	4
Green beans	Export	17	65%	13	9	11	11	4
Tomato	Multi-use	12	65%	9	4	9	9	4
Coffee	Export	26	57%	18	9	16	16	4
Beans	Subsistence	37	48%	31	12	14	14	4
Corn	Subsistence	42	35%	37	18	2	2	4
Guisantes	Multi-use	12	33%	8	0	4	4	3
Carrot	Multi-use	5	25%	5	0	0	0	1
Guisquil squash	Multi-use	42	18%	16	5	5	5	4
Chili	Multi-use	27	16%	7	1	5	4	4
Rabano	Multi-use	13	10%	4	0	1	0	2
Herbs	Multi-use	39	8%	11	1	0	0	2
Ayote	Multi-use	25	6%	4	1	0	1	3
Cardamom	Export	17	6%	1	1	1	1	4
Foreign Tomato	Export	23	4%	2	0	1	1	3
Chilacayote	Multi-use	27	4%	4	0	0	0	1
Hojas de Mosh	Multi-use	39	3%	2	1	1	1	4
Pine tree	Export	39	3%	1	1	1	1	4
Taro	Multi-use	40	3%	2	2	0	0	2
Camote	Multi-use	13	2%	1	0	0	0	1
Onion	Multi-use	18	1%	1	0	0	0	1
Banana	Multi-use	29	1%	1	0	0	0	1
Peach	Subsistence	40	0%	0	0	0	0	0
Guyaba	Subsistence	12	0%	0	0	0	0	0
Arakacha	Subsistence	12	0%	0	0	0	0	0
Yucca	Subsistence	12	0%	0	0	0	0	0
Avocado	Multi-use	32	0%	0	0	0	0	0
Pacaya	Multi-use	31	0%	0	0	0	0	0
Sugar Cane	Multi-use	26	0%	0	0	0	0	0
Orange	Multi-use	23	0%	0	0	0	0	0
Plum	Multi-use	15	0%	0	0	0	0	0
Pineapple	Multi-use	13	0%	0	0	0	0	0
Coyou	Multi-use	12	0%	0	0	0	0	0
Passionfruit	Multi-use	9	0%	0	0	0	0	0

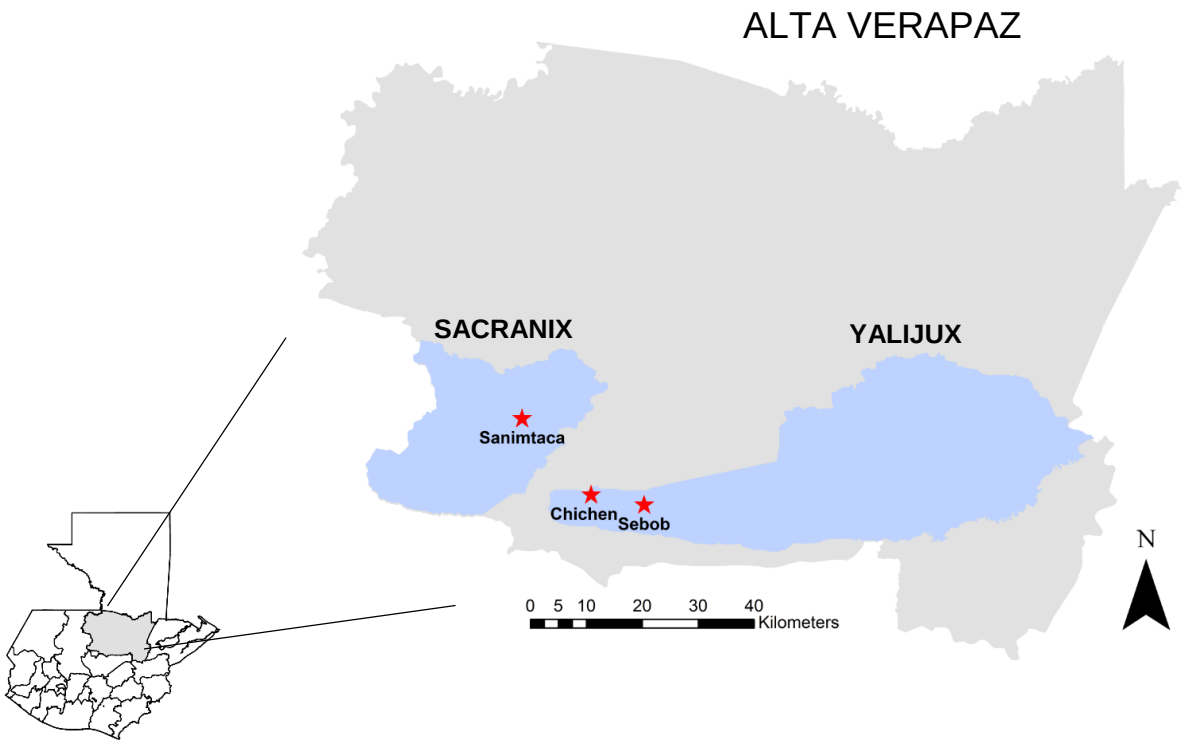

Figure 3.1: Study area in the Department of Alta Verapaz, Guatemala, two Important Bird Areas, the Sacranix and Yalijux mountain ranges, and three village sites, Sanimtaca, Chichen, and Sebob.

Figure 3.2a: Photo of Sebob and the agricultural landscape (broccoli). Photo by Gemara Gifford.

Figure 3.2b: Photo of Sanimtaca and the agricultural landscape. Photo by Gemara Gifford.

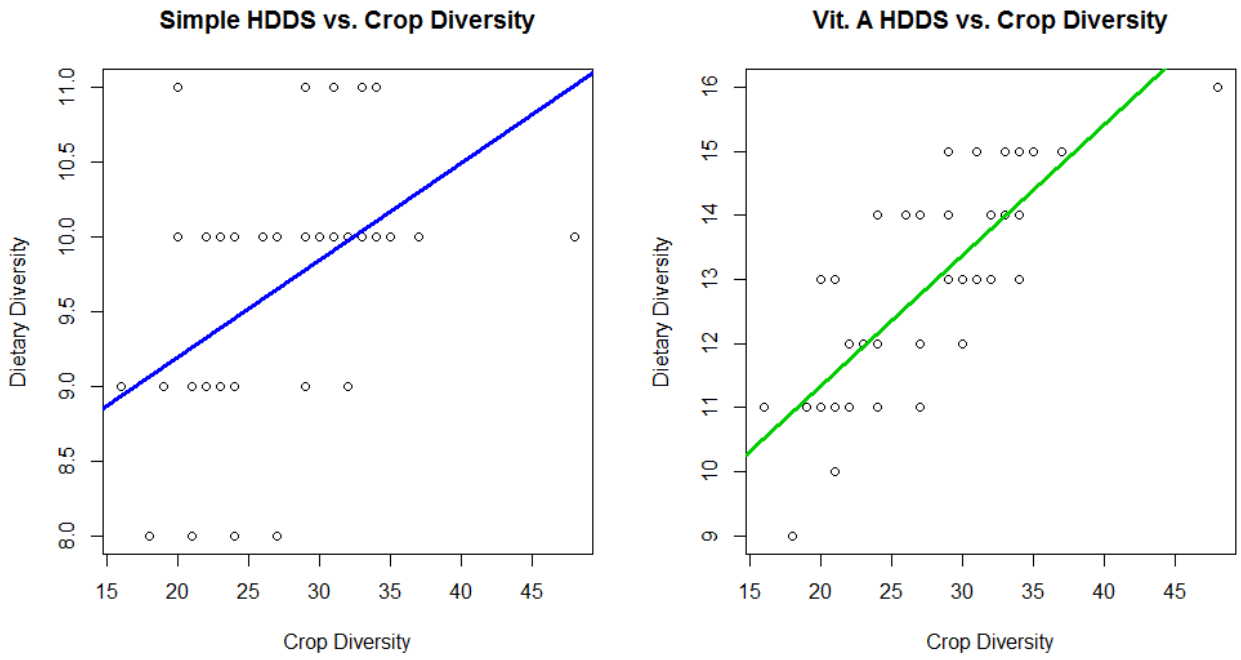

Figure 3.3 Dietary diversity is significantly related to crop diversity for both the Simple and Vitamin A Weighted HDDS from 42 household surveys in the Department of Alta Verapaz, Guatemala. Simple HDDS (β= 0.065 ± 0.020 SE, $F_{1,40} = 10.9$, P = 0.002); Vitamin-A HDDS (β= 0.020 ± 0.027 SE, $F1_{,40} = 57.48$, P = <0.001)

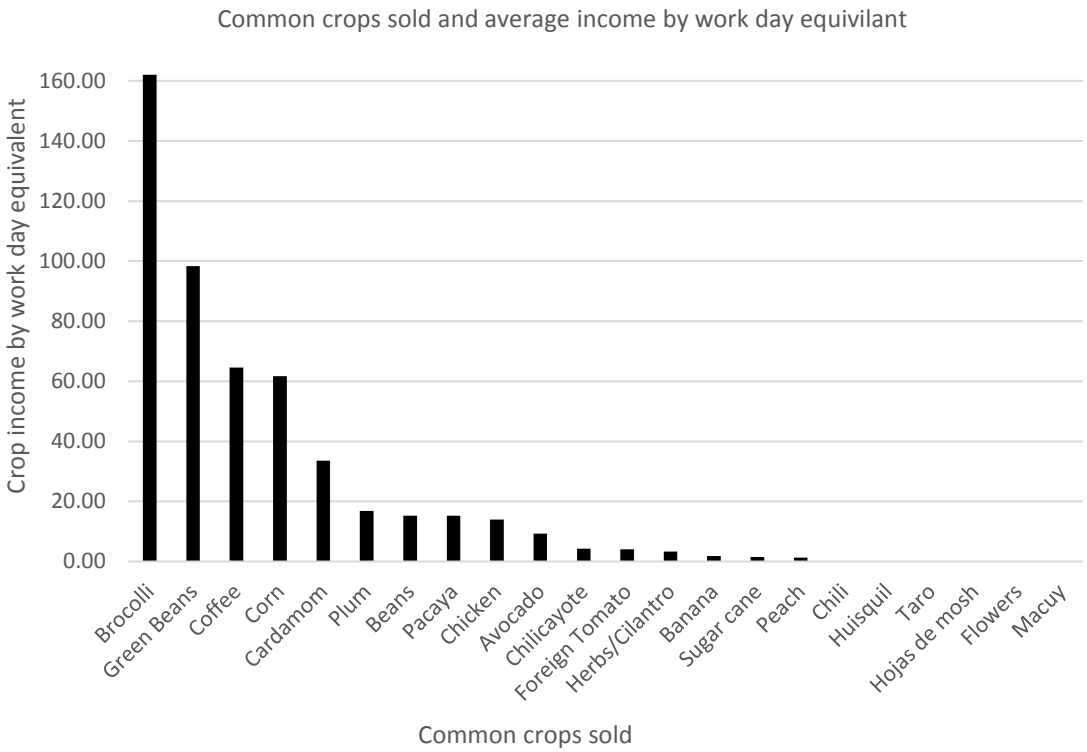

Figure 3.4: Export crops and corn generate the highest income by work-day equivalent (1 day = Q50.00) while fruits and heirloom varieties generate the least in the Department of Alta Verapaz, Guatemala 2014-2015. Common is defined by at least 5 households selling the crop. Standard errors are reported in Table 3.6.

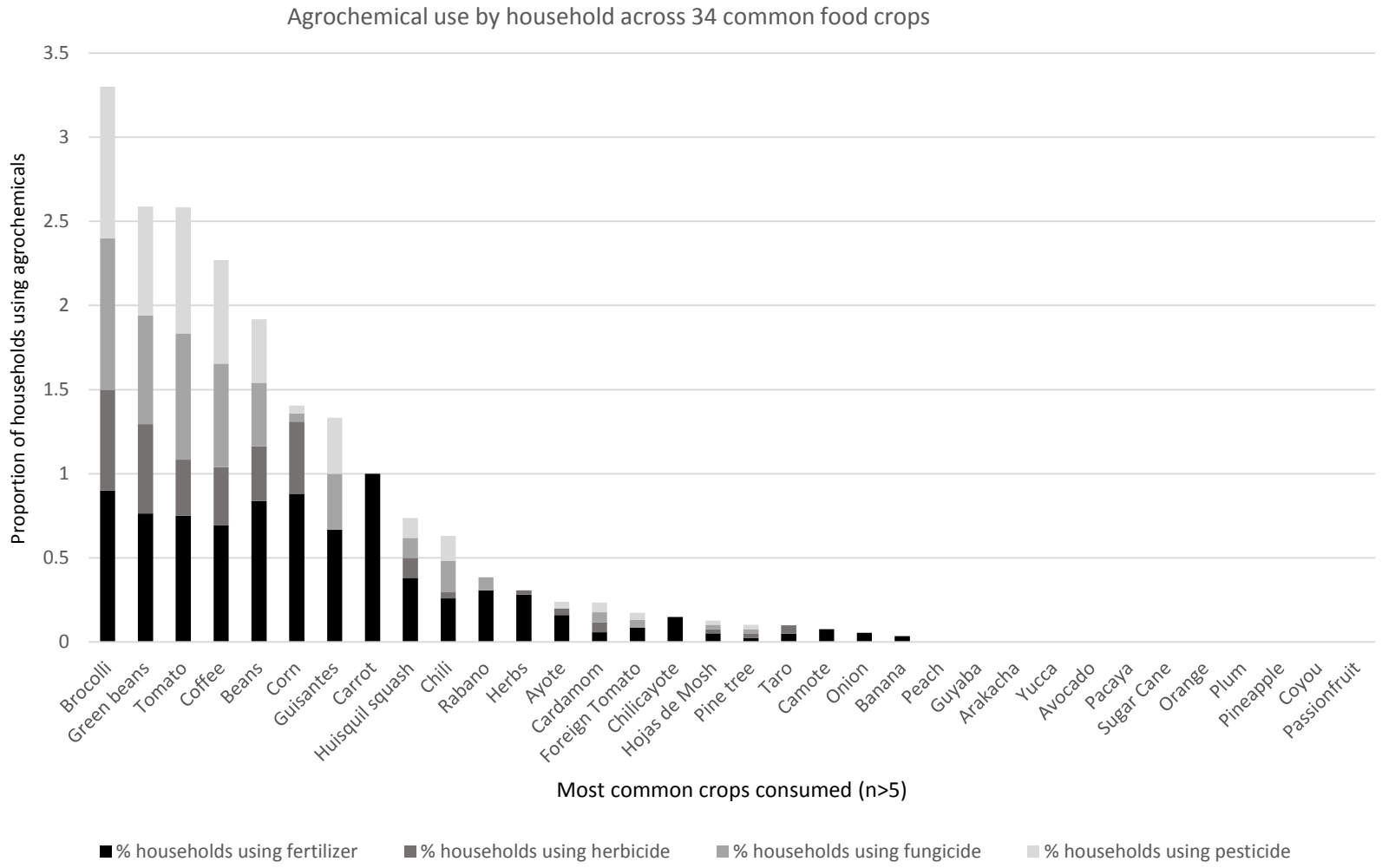

Figure 3.5: Export and milpa crops have the highest proportion of households using agrochemicals while nine fruit trees, 2 heirloom vegetables, and sugar cane required no chemical inputs in the Department of Alta Verapaz, Guatemala. Note: wild harvested goods are not shown though require no inputs. Reference Table 3.7 for specific values.

APPENDIX A: Expanded focal migrant, endemic, and forest species list (n = 68) from 2014 and 2015 surveys in Alta Verapaz, Guatemala. All species listed were observed at least once.

Count	English Common Name	Scientific Name	Guild
1	Azure-crowned Hummingbird	*Amazilia cyanocephala*	Forest
2	Baltimore Oriole	*Icterus galbula*	Migrant
3	Black-and-white Warbler	*Mniotilta varia*	Migrant
4	Black-throated Green Warbler	*Setophaga virens*	Migrant
5	Black-throated Jay	*Cyanolyca pumilo*	Forest
6	Blue-and-white Mockingbird	*Melanotis hypoleucus*	Endemic
7	Blue-crowned Chlorophonia	*Chlorophonia occipitalis*	Forest
8	Blue-crowned Motmot	*Momotus coeruliceps*	Forest
9	Blue-headed Vireo	*Vireo solitarius*	Migrant
10	Blue-throated Motmot	*Aspatha gularis*	Endemic
11	Brown-backed Solitaire	*Myadestes occidentalis*	Forest
12	Brown-capped Vireo	*Vireo leucophrys*	Forest
13	Buffy-crowned Wood-Partridge	*Dendrortyx leucophrys*	Forest
14	Bushy-crested Jay	*Cyanocorax melanocyaneus*	Endemic
15	Chestnut-capped Brush-Finch	*Arremon brunneinucha*	Forest
16	Cinnamon-bellied Flowerpiercer	*Diglossa baritula*	Forest
17	Collared Trogon	*Trogon collaris*	Forest
18	Common Chlorospingus	*Chlorospingus flavopectus*	Forest
19	Common Yellowthroat	*Geothlypis trichas*	Migrant
20	Crimson-collared Tanager	*Ramphocelus sanguinolentus*	Forest
21	Elegant Euphonia	*Euphonia elegantissima*	Forest
22	Emerald Toucanet	*Aulacorhynchus prasinus*	Forest
23	Golden-browed Warbler	*Basileuterus belli*	Forest
24	**Golden-cheeked Warbler**	***Setophaga chrysoparia***	**Migrant (EN)**
25	Golden-olive Woodpecker	*Colaptes rubiginosus*	Forest
26	**Golden-winged Warbler**	***Vermivora chrysoptera***	**Migrant (NT)**
27	Gray Catbird	*Dumetella carolinensis*	Migrant
28	Gray-breasted Wood-Wren	*Henicorhina leucophrys*	Forest
29	Greater Pewee	*Contopus pertinax*	Forest
30	Green-throated Mountain-gem	*Lampornis viridipallens*	Endemic
31	Hammond's Flycatcher	*Empidonax hammondii*	Migrant
32	Hermit Warbler	*Setophaga occidentalis*	Migrant
33	**Highland Guan**	***Penelopina nigra***	**Forest (VU)**
34	Indigo Bunting	*Passerina cyanea*	Migrant
35	Killdeer	*Charadrius vociferus*	Migrant
36	Lincoln's Sparrow	*Melospiza lincolnii*	Migrant

Appendix A continued:

37	Louisiana Waterthrush	*Parkesia motacilla*	Migrant
38	MacGillivray's Warbler	*Geothlypis tolmiei*	Migrant
39	Magnolia Warbler	*Setophaga magnolia*	Migrant
40	Mottled Owl	*Ciccaba virgata*	Forest
41	**Ocellated Quail**	***Cyrtonyx ocellatus***	**Endemic (VU)**
42	Paltry Tyrannulet	*Zimmerius vilissimus*	Forest
43	Philadelphia Vireo	*Vireo philadelphicus*	Migrant
44	Plain Chachalaca	*Ortalis vetula*	Forest
45	Prevost's Ground-Sparrow	*Melozone biarcuata*	Near-endemic
46	**Resplendent Quetzal**	***Pharomachrus mocinno***	**Forest (NT)**
47	Rose-breasted Grosbeak	*Pheucticus ludovicianus*	Migrant
48	Ruddy Foliage-gleaner	*Clibanornis rubiginosus*	Forest
49	Ruddy-capped Nightingale-Thrush	*Catharus frantzii*	Forest
50	Rufous-browed Wren	*Troglodytes rufociliatus*	Endemic
51	Rufous-collared Robin	*Turdus rufitorques*	Endemic
52	Scaly-throated Foliage-gleaner	*Anabacerthia variegaticeps*	Forest
53	Slate-colored Solitaire	*Myadestes unicolor*	Forest
54	Slate-throated Redstart	*Myioborus miniatus*	Forest
55	Spot-crowned Woodcreeper	*Lepidocolaptes affinis*	Forest
56	Spotted Nightingale-Thrush	*Catharus dryas*	Forest
57	Spotted Woodcreeper	*Xiphorhynchus erythropygius*	Forest
58	Stripe-throated Hermit	*Phaethornis striigularis*	Forest
59	Tawny-throated Leaftosser	*Sclerurus mexicanus*	Forest
60	Tennessee Warbler	*Oreothlypis peregrina*	Migrant
61	Townsend's Warbler	*Setophaga townsendi*	Migrant
62	Tufted Flycatcher	*Mitrephanes phaeocercus*	Forest
63	Violet Sabrewing	*Campylopterus hemileucurus*	Forest
64	White-eared Hummingbird	*Hylocharis leucotis*	Forest
65	Wilson's Warbler	*Cardellina pusilla*	Migrant
66	**Wood Thrush**	***Hylocichla mustelina***	**Migrant (WL)**
67	Yellow-bellied Flycatcher	*Empidonax flaviventris*	Migrant
68	Yellowish Flycatcher	*Empidonax flavescens*	Forest

APPENDIX B: Candidate model set used for single-species single-season occupancy models. Models increase in complexity based on the number of detection covariates used. Models include at least one of four detection covariates, except the constant detection model, and only a single occupancy covariate of seven. Each occupancy covariate is modeled with a total of 12 corresponding detection models for a total of 84 models for the 2015 season and 42 for the 2014 season.

DETECTION SUBMODEL						OCCUPANCY SUBMODEL
Model	*p*(.)	*p*(Count Type)*	*p*(Canopy Cover)	*p*(Time)	*p*(Time^2)	x_i (i.e. tree density)†
1	X					X
2		X				X
3			X			X
4				X		X
5		X		X		X
6			X	X		X
7		X	X			X
8		X	X	X		X
9				X	X	X
10		X		X	X	X
11			X	X	X	X
12		X	X	X	X	X

***** Count type was not included as a covariate during the 2014 monitoring season because only a single survey type was used (i.e. passive).

† x_i = occupancy covariates including four microhabitat variables and three landscape-level variables noted in Table 2.5.

Appendix C: Table of significant relationships between occupancy and seven habitat covariates for focal species during resident breeding and non-breeding seasons in the highlands of the Department of Alta Verapaz, Guatemala in 2015. Model coefficients (β ± SE) indicate a significant relationship between the covariate and occupancy based on 95% confidence limits, and the model $<2\Delta AIC_c$. Each significant relationship is visualized in Figures 2.6a-2.6c, and Table 6.

Focal Species	Scientific Name	Guild	Season	†β ± SE
	Ψ(Canopy cover)			
Black-and-white Warbler	*Mniotilta varia*	Migrant	NB	0.0176 ± 0.065
Common Yellowthroat	*Geothlypis trichas*	Migrant	NB	-0.084 ± 0.027
Green-throated Mountain-gem	*Lampornis viridipallens*	Endemic	NB	0.100 ± 0.034
Lincoln's Sparrow	*Melospiza lincolnii*	Migrant	NB	-0.103 ± 0.030
Slate-colored Solitaire	*Myioborus miniatus*	Forest	NB	0.066 ± 0.017
Common Cholorospingus	*Chlorospingus flavopectus*	Forest	B	0.093 ± 0.017
Grey-breasted Wood-wren	*Dumetella carolinensis*	Forest	B	0.066 ± 0.012
Green-throated Mountain-gem	*Lampornis viridipallens*	Endemic	B	0.118 ± 0.044
	Ψ(Trees/ha)			
Blue-headed Vireo	*Vireo solitarius*	Migrant	NB	0.023 ± 0.010
Slate-throated Redstart	*Anabacerthia variegaticeps*	Forest	B	0.002 ± 0.0007
	Ψ(% Height under 1m)			
Common Cholorospingus	*Chlorospingus flavopectus*	Forest	NB	-0.098 ± 0.029
Slate-throated Redstart	*Anabacerthia variegaticeps*	Forest	B	-0.043 ± 0.014
	Ψ(Epiphyte score)			
Grey-breasted Wood-wren	*Dumetella carolinensis*	Forest	B	0.145 ± 0.034
Slate-colored Solitaire	*Myioborus miniatus*	Forest	B	0.167 ± 0.056
	Ψ(% Cloud forest in 100-ha)			
Blue-and-white Mockingbird	*Melanotis hypoleucus*	Endemic	NB	-0.146 ± 0.062
Grey-breasted Wood-wren	*Dumetella carolinensis*	Forest	NB	0.270 ± 0.188
Scaly-throated Foliage-gleaner	*Myadestes unicolor*	Forest	NB	0.146 ± 0.109
Blue-and-white Mockingbird	*Melanotis hypoleucus*	Endemic	B	-0.106 ± 0.033
Rufous-collared Robin	*Turdus rufitorques*	Endemic	B	-0.097 ± 0.042
Slate-colored Solitaire	*Myioborus miniatus*	Forest	B	0.096 ± 0.040
	Ψ(% Mixed forest in 100-ha)			
Gray Catbird	*Henicorhina leucophrys*	Migrant	NB	-0.387 ± 0.014
Rufous-collared Robin*	*Turdus rufitorques*	Endemic	NB	-0.082 ± 0.046
	Ψ(Distance to cloud forest)			
Blue-and-white Mockingbird	*Melanotis hypoleucus*	Endemic	NB	0.012 ± 0.004
Rufous-collared Robin	*Turdus rufitorques*	Endemic	B	0.0044 ± 0.0018
Scaly-throated Foliage-gleaner	*Myadestes unicolor*	Forest	B	0.066 ± 0.022
Slate-colored Solitaire	*Myioborus miniatus*	Forest	B	-0.0056 ± 0.0019

*90% confidence limit used; †coefficients based off of graphed models in Figure 2.6.

APPENDIX D: Comparison of top-ranked models (up to 5 ΔAIC_c) and the null model explaining occupancy and detection for 15 focal species during resident breeding (June-August 2014) and non-breeding (January-February 2015) seasons. Covariate abbreviations used for detection (p) and occupancy (Ψ) are shown in Table 2.4. Bold text indicates the top-ranked models.

Model	K	Log-likelihood	AICc	ΔAICc	wi
Blue-and-white Mockingbird		(resident breeding)			
Ψ(PC) p(T+ T^2)	**5**	**-133.82**	**278.08**	**0.00**	**0.41**
Ψ(PC) p(T+ T^2 + CC)	**6**	**-133.35**	**279.33**	**1.25**	**0.22**
Ψ(PC) p(.)	3	-137.03	280.23	2.15	0.14
Ψ(PC) p(CC)	4	-136.29	280.86	2.78	0.10
Ψ(PC) p(T)	4	-136.72	281.73	3.65	0.07
Ψ(PC) p(T + CC)	5	-136.05	282.54	4.46	0.04
Ψ(.) p(.) Null Model	2	-148.86	301.80	23.72	0.00
Bushy-crested Jay		(resident breeding)			
Ψ(TD) p(T)	**4**	**-184.15**	**376.59**	**0.00**	**0.14**
Ψ(TD) p(T+ T^2)	**5**	**-183.23**	**376.90**	**0.32**	**0.12**
Ψ(TD) p(T + CC)	**5**	**-183.87**	**378.19**	**1.60**	**0.06**
Ψ(.) p(T)	**3**	**-186.07**	**378.32**	**1.73**	**0.06**
Ψ(TD) p(T+ T^2 + CC)	6	-182.99	378.59	2.01	0.05
Ψ(.) p(T+ T^2)	4	-185.16	378.61	2.02	0.05
Ψ(PM) p(T)	4	-185.24	378.77	2.18	0.05
Ψ(ES) p(T)	4	-185.53	379.36	2.77	0.04
Ψ(PM) p(T+ T^2)	5	-184.51	379.47	2.88	0.03
Ψ(ES) p(T+ T^2)	5	-184.53	379.51	2.92	0.03
Ψ(PC) p(T)	4	-185.72	379.74	3.15	0.03
Ψ(PC) p(T+ T^2)	5	-184.85	380.14	3.55	0.02
Ψ(DC) p(T)	4	-185.96	380.22	3.63	0.02
Ψ(.) p(T + CC)	4	-186.00	380.29	3.70	0.02
Ψ(VH) p(T)	4	-186.02	380.32	3.73	0.02
Ψ(CC) p(T)	4	-186.05	380.40	3.81	0.02
Ψ(.) p(T+ T^2 + CC)	5	-185.07	380.59	4.00	0.02
Ψ(VH) p(T+ T^2)	5	-185.08	380.60	4.01	0.02
Ψ(DC) p(T+ T^2)	5	-185.08	380.60	4.01	0.02
Ψ(CC) p(T+ T^2)	5	-185.13	380.71	4.12	0.02
Ψ(PM) p(T + CC)	5	-185.23	380.90	4.31	0.02
Ψ(PC) p(T + CC)	5	-185.32	381.09	4.50	0.01
Ψ(ES) p(T + CC)	5	-185.45	381.34	4.75	0.01
Ψ(ES) p(T+ T^2 + CC)	6	-184.39	381.40	4.82	0.01
Ψ(PC) p(T+ T^2 + CC)	6	-184.41	381.44	4.85	0.01
Ψ(.) p(.) Null Model	2	-190.67	385.43	8.84	0.00
Common Chlorospingus		(resident breeding)			
Ψ(CC) p(T + CC)	**5**	**-145.93**	**302.29**	**0.00**	**0.24**
Ψ(CC) p(CC)	**4**	**-147.07**	**302.43**	**0.14**	**0.23**
Ψ(CC) p(T+ T^2 + CC)	**6**	**-144.96**	**302.53**	**0.24**	**0.22**
Ψ(CC) p(T)	**4**	**-147.84**	**303.97**	**1.68**	**0.11**
Ψ(CC) p(.)	**3**	**-148.91**	**303.99**	**1.70**	**0.10**
Ψ(CC) p(T+ T^2)	**5**	**-146.80**	**304.04**	**1.75**	**0.10**
Ψ(.) p(.) Null Model	2	-183.22	370.53	68.24	0.00

Appendix D Continued:

Grey-breasted Wood-wren			(resident breeding)		
Ψ(PC) p(ES)	**4**	**-214.30**	**436.89**	**0.00**	**0.30**
Ψ(ES) p(T + CC)	**5**	**-213.49**	**437.43**	**0.54**	**0.23**
Ψ(CC) p(CC)	**4**	**-214.82**	**437.94**	**1.05**	**0.18**
Ψ(CC) p(T + CC)	5	-214.28	439.01	2.12	0.10
Ψ(ES) p(T+ T^2 + CC)	6	-213.48	439.59	2.69	0.08
Ψ(PC) p(CC)	4	-216.28	440.84	3.95	0.04
Ψ(CC) p(T+ T^2 + CC)	6	-214.26	441.14	4.25	0.04
Ψ(PC) p(T + CC)	5	-215.43	441.31	4.42	0.03
Ψ(.) p(.) Null Model	2	-249.69	503.48	66.58	0.00
Green-throated Mountain-gem			(resident breeding)		
Ψ(CC) p(T)	**4**	**-49.97**	**108.24**	**0.00**	**0.83**
Ψ(DC) p(T)	4	-51.56	111.41	3.17	0.17
Ψ(.) p(.) Null Model	2	-71.48	147.05	38.81	0.00
Rufous-collared Robin			(resident breeding)		
Ψ(DC) p(.)	**3**	**-62.27**	**130.72**	**0.00**	**0.34**
Ψ(PC) p(.)	**3**	**-62.97**	**132.12**	**1.39**	**0.17**
Ψ(DC) p(CC)	**4**	**-62.02**	**132.34**	**1.61**	**0.15**
Ψ(DC) p(T)	**4**	**-62.03**	**132.36**	**1.63**	**0.15**
Ψ(PC) p(CC)	4	-62.78	133.86	3.13	0.07
Ψ(PC) p(T)	4	-62.80	133.89	3.17	0.07
Ψ(.) p(.) Null Model	2	-68.24	140.57	9.85	0.00
Scaly-throated Foliage-gleaner			(resident breeding)		
Ψ(DC) p(.)	**3**	**-87.80**	**181.78**	**0.00**	**0.55**
Ψ(DC) p(T)	**4**	**-87.35**	**182.98**	**1.21**	**0.30**
Ψ(DC) p(T+ T^2)	5	-87.31	185.06	3.29	0.11
Ψ(.) p(.) Null Model	2.00	-123.42	250.93	69.16	0.00
Slate-colored Solitaire			(resident breeding)		
Ψ(ES) p(T+ T^2 + CC)	**6**	**-140.08**	**292.77**	**0.00**	**0.58**
Ψ(PC) p(T+ T^2 + CC)	**6**	**-140.76**	**294.13**	**1.36**	**0.30**
Ψ(DC) p(T+ T^2 + CC)	6	-141.76	296.14	3.37	0.11
Ψ(.) p(.) Null Model	2	-191.93	387.95	95.18	0.00
Slate-throated Redstart			(resident breeding)		
Ψ(TD) p(.)	**3**	**-199.01**	**404.19**	**0.00**	**0.15**
Ψ(VH) p(CC)	**4**	**-198.09**	**404.46**	**0.27**	**0.13**
Ψ(TD) p(CC)	**4**	**-198.19**	**404.67**	**0.48**	**0.12**
Ψ(VH) p(.)	**3**	**-199.42**	**405.01**	**0.82**	**0.10**
Ψ(TD) p(T)	**4**	**-198.66**	**405.62**	**1.43**	**0.07**
Ψ(VH) p(CT)	**5**	**-197.82**	**406.07**	**1.88**	**0.06**
Ψ(TD) p(T + CC)	5	-197.91	406.26	2.07	0.05
Ψ(VH) p(T+ T^2 + CC)	6	-196.86	406.34	2.15	0.05
Ψ(VH) p(T)	4	-199.10	406.49	2.30	0.05
Ψ(TD) p(T+ T^2 + CC)	6	-196.95	406.52	2.33	0.05
Ψ(TD) p(T+ T^2)	5	-198.05	406.54	2.35	0.05
Ψ(VH) p(T+ T^2)	5	-198.57	407.58	3.39	0.03
Ψ(CC) p(.)	3	-201.25	408.67	4.48	0.02
Ψ(.) p(.) Null Model	2	-205.19	414.47	10.27	0.00

Appendix D Continued:

Model	K	Log-likelihood	AICc	ΔAICc	wi
Black-and-white Warbler		(resident non-breeding season)			
Ψ(CC) p(CT + CC)	**5**	**-107.71**	**225.86**	**0.00**	**0.45**
Ψ(CC) p(CT)	**4**	**-109.40**	**227.09**	**1.24**	**0.24**
Ψ(CC) p(T+ CT + CC)	6	-107.71	228.04	2.18	0.15
Ψ(CC) p(T + CT)	5	-109.40	229.24	3.38	0.08
Ψ(DC) p(CT + CC)	5	-110.02	230.49	4.63	0.04
Ψ(.) p(.) Null Model	2	-125.15	254.40	28.54	0.00
Blue-and-white Mockingbird		(resident non-breeding season)			
Ψ(PC) p(.)	**3**	**-85.56**	**177.29**	**0.00**	**0.18**
Ψ(DC) p(.)	**3**	**-85.68**	**177.54**	**0.25**	**0.16**
Ψ(PC) p(CT)	**4**	**-85.23**	**178.76**	**1.47**	**0.09**
Ψ(DC) p(CT)	**4**	**-85.29**	**178.88**	**1.59**	**0.08**
Ψ(DC) p(CC)	**4**	**-85.33**	**178.96**	**1.67**	**0.08**
Ψ(PC) p(CC)	**4**	**-85.35**	**179.00**	**1.71**	**0.08**
Ψ(PC) p(T)	**4**	**-85.45**	**179.20**	**1.91**	**0.07**
Ψ(DC) p(T)	4	-85.61	179.52	2.23	0.06
Ψ(PC) p(T + CT)	5	-84.82	180.09	2.80	0.04
Ψ(DC) p(T + CT)	5	-84.93	180.30	3.01	0.04
Ψ(DC) p(CT + CC)	5	-84.98	180.40	3.11	0.04
Ψ(PC) p(CT + CC)	5	-85.02	180.49	3.20	0.04
Ψ(DC) p(T + CC)	5	-85.27	180.97	3.68	0.03
Ψ(PC) p(T + CC)	5	-85.27	180.98	3.69	0.03
Ψ(.) p(.) Null Model	2	-95.33	194.74	17.45	0.00
Blue-headed Vireo		(resident non-breeding season)			
Ψ(TD) p(CT + CC)	**5**	**-103.14**	**216.72**	**0.00**	**0.53**
Ψ(TD) p(CT)	4	-105.29	218.87	2.16	0.18
Ψ(TD) p(T + CT)	5	-104.59	219.62	2.90	0.13
Ψ(CC) p(T + CT)	5	-105.16	220.77	4.05	0.07
Ψ(.) p(.) Null Model	2	-122.39	248.87	32.16	0.00
Bushy-crested Jay		(resident non-breeding season)			
Ψ(PC) p(T+ T^2 + CT)	**6**	**-266.11**	**544.85**	**0.00**	**0.16**
Ψ(PC) p(T+ T^2)	**5**	**-267.24**	**544.91**	**0.06**	**0.15**
Ψ(CC) p(T+ T^2)	5	-268.24	546.93	2.07	0.06
Ψ(CC) p(T+ T^2 + CT)	6	-267.25	547.12	2.26	0.05
Ψ(PC) p(T + CT)	5	-268.70	547.85	3.00	0.04
Ψ(PM) p(T+ T^2)	5	-268.88	548.21	3.35	0.03
Ψ(DC) p(T+ T^2 + CT)	6	-267.90	548.42	3.57	0.03
Ψ(PM) p(T+ T^2 + CT)	6	-268.02	548.66	3.80	0.02
Ψ(ES) p(T+ T^2)	5	-269.32	549.08	4.23	0.02
Ψ(PM) p(T+ T^2 + CC)	6	-268.36	549.35	4.49	0.02
Ψ(TD) p(T+ T^2)	5	-269.47	549.39	4.54	0.02
Ψ(VH) p(T+ T^2)	5	-269.49	549.42	4.57	0.02
Ψ(ES) p(T+ T^2 + CT)	6	-268.44	549.50	4.65	0.02

Appendix D Continued:

Ψ(DC) p(T+ T^2)	5	-269.53	549.51	4.66	0.02
Ψ(PC) p(.)	3	-271.74	549.66	4.80	0.01
Ψ(PM) p(T+ T^2 + CT + CC)	7	-267.42	549.68	4.83	0.01
Ψ(.) p(.) Null Model	2	-273.44	550.97	6.11	0.01
Common Chlorospingus		(resident non-breeding season)			
Ψ(VH) p(CC)	**4**	**-222.01**	**452.32**	**0.00**	**0.23**
Ψ(VH) p(CT)	**5**	**-221.46**	**453.36**	**1.04**	**0.14**
Ψ(VH) p(T+ CT + CC)	**6**	**-220.46**	**453.54**	**1.22**	**0.12**
Ψ(VH) p(CT + CC)	**5**	**-221.57**	**453.59**	**1.27**	**0.12**
Ψ(VH) p(T+ T^2 + CC)	6	-221.29	455.21	2.89	0.05
Ψ(PC) p(CC)	4	-223.55	455.40	3.07	0.05
Ψ(VH) p(T+ T^2 + CT + CC)	7	-220.33	455.51	3.19	0.05
Ψ(PC) p(T+ CT + CC)	6	-221.76	456.14	3.82	0.03
Ψ(PC) p(CT + CC)	5	-222.87	456.19	3.87	0.03
Ψ(CC) p(CC)	4	-224.03	456.35	4.03	0.03
Ψ(PC) p(T + CC)	5	-223.06	456.57	4.25	0.03
Ψ(.) p(.) Null Model	2	-249.93	503.95	51.63	0.00
Common Yellowthroat		(resident non-breeding season)			
Ψ(CC) p(.)	**3**	**-76.22**	**158.61**	**0.00**	**0.22**
Ψ(CC) p(T)	**4**	**-75.51**	**159.32**	**0.71**	**0.16**
Ψ(CC) p(CC)	**4**	**-75.92**	**160.13**	**1.52**	**0.10**
Ψ(CC) p(T + CT)	**5**	**-75.02**	**160.49**	**1.88**	**0.09**
Ψ(CC) p(CT)	4	-76.19	160.68	2.07	0.08
Ψ(CC) p(T + CC)	5	-75.24	160.93	2.32	0.07
Ψ(PC) p(CC)	4	-76.64	161.57	2.96	0.05
Ψ(CC) p(T + CT)	5	-75.91	162.26	3.65	0.04
Ψ(PC) p(T + CC)	5	-75.92	162.28	3.67	0.04
Ψ(DC) p(CC)	4	-77.29	162.87	4.26	0.03
Ψ(PC) p(ES)	4	-77.38	163.05	4.44	0.02
Ψ(PM) p(CC)	4	-77.56	163.42	4.81	0.02
Ψ(DC) p(T + CC)	5	-76.57	163.59	4.98	0.02
Ψ(.) p(.) Null Model	2	-86.41	176.92	18.31	0.00
Gray Catbird		(resident non-breeding season)			
Ψ(PM) p(CT + CC)	**5**	**-166.68**	**343.81**	**0.00**	**0.45**
Ψ(PM) p(CC)	**4**	**-168.72**	**345.74**	**1.93**	**0.17**
Ψ(PM) p(T + CT + CC)	6	-166.56	345.75	1.94	0.17
Ψ(PM) p(T + CC)	5	-167.85	346.15	2.34	0.14
Ψ(.) p(.) Null Model	2	-183.67	371.43	27.61	0.00
Grey-breasted Wood-wren		(resident non-breeding season)			
Ψ(PC) p(T+ T^2 + CC)	**6**	**-255.67**	**523.97**	**0.00**	**0.32**
Ψ(PC) p(CC)	**4**	**-258.02**	**524.32**	**0.35**	**0.27**
Ψ(PC) p(T + CC)	5	-257.84	526.12	2.14	0.11
Ψ(PC) p(T+ T^2 + CT + CC)	7	-255.66	526.17	2.19	0.11
Ψ(PC) p(CT + CC)	5	-258.00	526.44	2.46	0.09
Ψ(PC) p(T+ CT + CC)	6	-257.84	528.30	4.33	0.04
Ψ(.) p(.) Null Model	2	-297.13	598.35	74.37	0.00

Appendix D Continued:

Green-throated Mountain-gem		(resident non-breeding season)			
Ψ(CC) p(CC)	**4**	**-148.73**	**305.76**	**0.00**	**0.27**
Ψ(CC) p(CT + CC)	**5**	**-148.35**	**307.15**	**1.39**	**0.13**
Ψ(CC) p(T + CC)	**5**	**-148.45**	**307.35**	**1.59**	**0.12**
Ψ(CC) p(.)	3	-151.02	308.21	2.45	0.08
Ψ(DC) p(.)	3	-151.26	308.70	2.93	0.06
Ψ(PC) p(ES)	4	-150.58	309.46	3.70	0.04
Ψ(DC) p(CT)	4	-150.64	309.57	3.81	0.04
Ψ(CC) p(CT)	4	-150.72	309.74	3.98	0.04
Ψ(CC) p(T)	4	-150.73	309.76	3.99	0.04
Ψ(ES) p(CT + CC)	5	-149.92	310.28	4.52	0.03
Ψ(DC) p(T)	4	-151.03	310.35	4.59	0.03
Ψ(DC) p(T + CT)	5	-149.97	310.38	4.62	0.03
Ψ(CC) p(T + CT)	5	-150.13	310.70	4.94	0.02
Ψ(.) p(.) Null Model	2	-183.58	371.25	65.49	0.00
Lincoln's Sparrow		(resident non-breeding season)			
Ψ(CC) p(.)	**3**	**-81.56**	**169.29**	**0.00**	**0.30**
Ψ(CC) p(CT)	**4**	**-81.33**	**170.95**	**1.66**	**0.13**
Ψ(CC) p(T)	**4**	**-81.45**	**171.20**	**1.91**	**0.11**
Ψ(CC) p(CC)	4	-81.55	171.40	2.11	0.10
Ψ(VH) p(CC)	4	-81.90	172.09	2.80	0.07
Ψ(CC) p(T + CT)	5	-81.32	173.09	3.80	0.04
Ψ(CC) p(CT + CC)	5	-81.32	173.09	3.80	0.04
Ψ(CC) p(T + CC)	5	-81.44	173.33	4.04	0.04
Ψ(VH) p(CT + CC)	5	-81.48	173.40	4.11	0.04
Ψ(VH) p(CT)	5	-81.63	173.70	4.41	0.03
Ψ(.) p(.) Null Model	2	-97.24	198.56	29.27	0.00
Rufous-collared Robin		(resident non-breeding season)			
Ψ(PC) p(T)	**4**	**-53.49**	**115.28**	**0.00**	**0.37**
Ψ(PM) p(.)	**3**	**-55.14**	**116.46**	**1.18**	**0.20**
Ψ(ES) p(.)	3	-55.70	117.58	2.30	0.12
Ψ(PM) p(CT)	4	-54.75	117.79	2.52	0.10
Ψ(PM) p(T)	4	-55.07	118.43	3.15	0.08
Ψ(.) p(.) Null Model	2	-57.30	118.68	3.40	0.07
Ψ(ES) p(T)	4	-55.26	118.82	3.55	0.06
Scaly-throated Foliage-gleaner		(resident non-breeding season)			
Ψ(PC) p(.)	**3**	**-72.02**	**150.21**	**0.00**	**0.25**
Ψ(PC) p(CC)	**4**	**-71.66**	**151.61**	**1.40**	**0.12**
Ψ(PC) p(CT)	**4**	**-71.68**	**151.64**	**1.44**	**0.12**
Ψ(PC) p(T)	4	-72.01	152.31	2.11	0.09
Ψ(DC) p(.)	3	-73.15	152.48	2.27	0.08
Ψ(PC) p(CT + CC)	5	-71.33	153.10	2.90	0.06
Ψ(DC) p(CC)	4	-72.52	153.34	3.14	0.05
Ψ(PC) p(T + CT)	5	-71.57	153.59	3.39	0.05
Ψ(PC) p(T + CC)	5	-71.65	153.75	3.54	0.04
Ψ(DC) p(CT)	4	-72.78	153.86	3.65	0.04
Ψ(DC) p(T)	4	-73.15	154.60	4.39	0.03
Ψ(DC) p(CT + CC)	5	-72.18	154.81	4.60	0.02

Appendix D Continued:

Ψ(.) p(.) Null Model	2	-87.96	180.01	29.81	0.00
Slate-colored Solitaire		(resident non-breeding season)			
Ψ(CC) p(CT)	**4**	**-117.83**	**243.96**	**0.00**	**0.36**
Ψ(CC) p(CT + CC)	**5**	**-117.71**	**245.86**	**1.90**	**0.14**
Ψ(CC) p(T + CT)	**5**	**-117.75**	**245.94**	**1.98**	**0.13**
Ψ(PC) p(CT)	4	-119.11	246.51	2.55	0.10
Ψ(PC) p(CT + CC)	5	-118.12	246.68	2.72	0.09
Ψ(CC) p(T+ CT + CC)	6	-117.62	247.87	3.91	0.05
Ψ(PC) p(T + CT)	5	-118.89	248.22	4.26	0.04
Ψ(PC) p(T+ CT + CC)	6	-117.87	248.37	4.40	0.04
Ψ(.) p(.) Null Model	2	-138.42	280.92	36.96	0.00
Slate-throated Redstart		(resident non-breeding season)			
Ψ(CC) p(CT + CC)	**5**	**-332.36**	**675.16**	**0.00**	**0.13**
Ψ(CC) p(T + CT)	**5**	**-332.50**	**675.44**	**0.28**	**0.12**
Ψ(CC) p(.)	**3**	**-334.87**	**675.92**	**0.75**	**0.09**
Ψ(CC) p(T+ CT + CC)	6	-332.36	677.34	2.18	0.05
Ψ(ES) p(CT + CC)	5	-333.49	677.41	2.25	0.04
Ψ(CC) p(T)	4	-334.56	677.42	2.25	0.04
Ψ(CC) p(T+ T^2 + CT)	6	-332.42	677.46	2.30	0.04
Ψ(ES) p(CT)	4	-334.64	677.58	2.41	0.04
Ψ(TD) p(CT)	4	-334.69	677.68	2.51	0.04
Ψ(CC) p(CC)	4	-334.76	677.81	2.65	0.04
Ψ(PM) p(CT + CC)	5	-333.85	678.15	2.99	0.03
Ψ(TD) p(CT + CC)	5	-333.90	678.24	3.07	0.03
Ψ(CC) p(T+ T^2 + CT + CC)	7	-332.26	679.36	4.20	0.02
Ψ(CC) p(T + CC)	5	-334.46	679.37	4.21	0.02
Ψ(CC) p(T+ T^2)	5	-334.49	679.43	4.26	0.02
Ψ(VH) p(CT + CC)	5	-334.53	679.50	4.34	0.02
Ψ(ES) p(T+ CT + CC)	6	-333.47	679.57	4.41	0.01
Ψ(ES) p(T + CT)	5	-334.63	679.71	4.55	0.01
Ψ(TD) p(T + CT)	5	-334.69	679.83	4.66	0.01
Ψ(DC) p(CT + CC)	5	-334.77	679.99	4.83	0.01
Ψ(PM) p(CC)	4	-335.89	680.08	4.91	0.01
Ψ(TD) p(.)	3	-336.95	680.08	4.91	0.01
Wood Thrush		(resident non-breeding season)			
Ψ(CC) p(CC)	**4**	**-101.42**	**211.13**	**0.00**	**0.13**
Ψ(CC) p(T + CT)	**5**	**-100.73**	**211.91**	**0.78**	**0.09**
Ψ(DC) p(.)	**3**	**-103.28**	**212.73**	**1.59**	**0.06**
Ψ(CC) p(T + CC)	**5**	**-101.31**	**213.07**	**1.93**	**0.05**
Ψ(PC) p(.)	3	-103.53	213.23	2.10	0.05
Ψ(TD) p(.)	3	-103.57	213.31	2.18	0.04
Ψ(DC) p(CT)	4	-102.66	213.62	2.48	0.04
Ψ(TD) p(CT)	4	-102.73	213.76	2.62	0.03
Ψ(PC) p(CT)	4	-102.80	213.89	2.75	0.03
Ψ(.) p(.) Null Model	2	-105.12	214.34	3.20	0.03
Ψ(DC) p(CC)	4	-103.03	214.35	3.22	0.03
Ψ(TD) p(T + CT)	5	-102.04	214.52	3.38	0.02
Ψ(DC) p(T)	4	-103.12	214.52	3.39	0.02
Ψ(CC) p(CT)	4	-103.13	214.55	3.42	0.02

Appendix D Continued:

Ψ(DC) p(T + CT)	5	-102.06	214.57	3.44	0.02
Ψ(PC) p(CC)	4	-103.24	214.77	3.64	0.02
Ψ(PC) p(T + CT)	5	-102.19	214.83	3.70	0.02
Ψ(PC) p(T)	4	-103.39	215.08	3.94	0.02
Ψ(TD) p(CC)	4	-103.39	215.08	3.95	0.02
Ψ(TD) p(T)	4	-103.40	215.10	3.97	0.02
Ψ(DC) p(CT + CC)	5	-102.35	215.14	4.01	0.02
Ψ(CC) p(T + CT)	5	-102.47	215.38	4.25	0.02
Ψ(PM) p(CC)	4	-103.55	215.40	4.26	0.02
Ψ(PC) p(CT + CC)	5	-102.50	215.44	4.31	0.02
Ψ(VH) p(CC)	4	-103.65	215.60	4.46	0.01
Ψ(TD) p(CT + CC)	5	-102.58	215.61	4.47	0.01
Ψ(PM) p(.)	3	-104.74	215.65	4.52	0.01
Ψ(VH) p(.)	3	-104.82	215.81	4.68	0.01
Ψ(CC) p(T)	4	-103.80	215.90	4.77	0.01
Ψ(PM) p(CT + CC)	5	-102.80	216.05	4.92	0.01
Ψ(VH) p(CT + CC)	5	-102.84	216.11	4.98	0.01

APPENDIX E: Example household questionnaire (Spanish) for on-farm crop diversity, dietary diversity, agrochemical use, and crop prices.

A. ALIMENTOS Y FIBRAS CULTIVADAS														
						vender	vender	vender						
1)	Sí	No	**2)** ¿Para comer?	**3)** ¿Para vender?	**4) #** cuerdas o arboles o animales?	**5)** ¿Unidad de medida?	**6)** ¿Precio por unidad?	**7)** ¿Cuántas unidades has vendido?	**8) ¿**Trabajo remunerado?	**9)** ¿Utiliza fertilizante?	**10)** ¿Utiliza herbicida?	**11)** ¿Utiliza fungicida?	**12)** ¿Utiliza pesticida?
I. VERDURAS			*S / N*	*S / N*					*S / N*	*S / N*	*S / N*	*S / N*	*S / N*
BRÓCOLI											Q		
FRIJOLES											Q		
HUISQUIL/PUNTAS DE											Q		
MAIZ											Q		
MALANGA											Q		
ARAKACHA											Q		
AYOTE											Q		
CAMOTE											Q		
CAÑA											Q		
CEBOLLIN											Q		
CHAMPIÑONES											Q		
CHILI											Q		
CHILICAYOTE											Q		
FRIJOLES VERDES											Q		
GUISANTES											Q		
HIERBAS (CILANTRO)											Q		
HOJAS DE MOSH											Q		
LECHUGA											Q		
RÁBANO											Q		
REMOLACHA											Q		
TOMATE											Q		
TOMATE EXTRANJERO											Q		
YUCCA											Q		
ZANAHORIA											Q		
_____											Q		
_____											Q		
_____											Q		
_____											Q		
_____											Q		

Appendix E continued:

A. ALIMENTOS Y FIBRAS CULTIVADAS														
						vender	vender	vender						
1)	Sí	No	2) ¿Para comer?	3) ¿Para vender?	4) ¿# cuerdas o arboles o animales?	5) ¿Unidad de medida?	6) ¿Precio por unidad?	7) ¿Cuántas unidades has vendido?	8) ¿Trabajo remunerado?	9) ¿Utiliza fertilizante?	10) ¿Utiliza herbicida?	11) ¿Utiliza fungicida?	12) ¿Utiliza pesticida?
II. FRUTAS			*S / N*	*S / N*					*S / N*	*S / N*	*S / N*	*S / N*	*S / N*
AGUACATE											Q		
BANANA											Q		
CIRUELA											Q		
DURAZNO											Q		
GRANADILLA											Q		
NARANJA											Q		
PIÑA											Q		
_____											Q		
_____											Q		
_____											Q		
_____											Q		
_____											Q		
III. OTROS			*S / N*	*S / N*					*S / N*	*S / N*	*S / N*	*S / N*	*S / N*
CAFÉ											Q		
CARDAMOMO											Q		
PLANTAS (PINO)											Q		
_____											Q		
_____											Q		
_____											Q		
IV. GANADOS			*S / N*	*S / N*					*S / N*				
GALLINA													
PAVO													
RES / VACA													
CERDO													
CABRA													
OVEJA													
CABALLO													
_____													
_____													

Appendix E continued:

B. ALIMENTOS Y FIBRAS SILVESTRES														
						vender	vender	vender						
	Sí	No	**2)** ¿Para comer?	**3)** ¿Para vender?	**4)** ¿Para usar en la casa	**5)** ¿Unidad de medida?	**6)** ¿Precio por unidad?	**7)** ¿Cuántas unidades has vendido?	**8)** ¿Trabajo remunerado?					
NOMBRE DE PRODUCTO			*S / N*	*S / N*	*S / N*				*S / N*					
LEÑA							Q							
MALANGA							Q							
QUIM HA							Q							
ROC-TIXL							Q							
FLORES							Q							
ANIMALES							Q							
TREE FERN							Q							
MACUY							Q							
TZOLOJL							Q							
_____							Q							
_____							Q							
_____							Q							
_____							Q							
_____							Q							

C. DEMOGRAFÍA							
1. ¿Cuál es el tamaño de su granja? (Cuerdas/Manzar	_____						
2. ¿Cuantos personas viven en su casa?	4	5	6	7	8	9	10
3. ¿Cuántos años tiene su hija mayor?	_____años						
4. ¿Cuál es su grado de educación?	Primario	Basico	Bachillerato				
5. ¿Cuántos años tiene su hijo mayor?	_____años						
6. ¿Cuál es su grado de educación?	Primario	Basico	Bachillerato				

APPENDIX F: Crop database from household surveys, with common, Q'eqchi', and scientific names for 68 foods and 6 fibers cultivated or harvested in Alta Verapaz, Guatemala.

Count	Crop Common Name	Q'eqchi' Name	Scientific Name	HDDS Food Group
1	Achiote / Annatto	Xayaw	*Bixa orellana*	Spices, condiments, and beverages
2	Albahaca / Basil		*Ocimum basilicum*	Spices, condiments, and beverages
3	Arakacha	Arakach		White roots and tubers
4	Arbejas			Other vegetables
5	Avocado	O'	*Persea americana*	Other fruits
6	Ayote squash	K'um	*Cucurbita moschata*	Vit.A rich vegetables and tubers
7	Banana	Tul	*Musa sapientum*	Other fruits
8	Beans	Lol	*Phaseolis coccineus*	Legumes, nuts, and seeds
9	Beet	Romolaach	*Beta vulgaris*	Other vegetables
10	Brocolli			Vit. A rich dark green leafy vegetables
11	Camote	Is	*Ipomea batata*	Vit.A rich vegetables and tubers
12	Cardamom	Tzi'	*Elettaria cardamomum*	Spices, condiments, and beverages
13	Carrot	Zanahoor	*Dacus carotum*	Vit.A rich vegetables and tubers
14	Chicken			Flesh meat
15	Chilacayote	Q'ooq'	*Cucurbita ficifolia*	Other vegetables
16	Chilga			Other fruits
17	Chili	Ik	*Caspicum frutescens*	Spices, condiments, and beverages
18	Chipilin			Spices, condiments, and beverages
19	Ch'onte'			Vit. A rich dark green leafy vegetables
20	Coffee	Kape'	*Coffea arabica*	Spices, condiments, and beverages
21	Corn	Ixim	*Zea mays*	Cereals
22	Cow			Flesh meat
23	Coyou	O'		Other fruits
24	Custard apple	Tz'umuy		Other fruits
25	Duck			Flesh meat
26	Flowers			N/A - Fiber
27	Foreign Tomato	Che'pix	*Cyphomandra betacea*	Other vegetables
28	Fuelwood			N/A - Fiber
29	Goat			Flesh meat
30	Green beans			Other vegetables
31	Guic			Vit.A rich vegetables and tubers
32	Guisantes			Other vegetables
33	Guyaba	Pa'ta	*Psidium guajava*	Other fruits
34	Herbs (cilantro)	Culantro	*Coriandrum sativum*	Spices, condiments, and beverages
35	Hojas de Mosh			Other vegetables
36	Huisquil squash	Ch'ima	*Sechium edule*	Vit.A rich vegetables and tubers
37	Injerto			Other fruits
38	Lemon	Lamunx	*Citrus aurantifolia*	Other fruits
39	Lime	Liim	*Citrus sp.*	Other fruits
40	Macademia			Legumes, nuts, and seeds
41	Mandarine		*Citrus reticulata*	Other fruits
42	Mango			Vit.A rich fruits
43	Nance			Other fruits
44	Nightshade	Macuy	*Solanum nigrescens*	Vit. A rich dark green leafy vegetables
45	Onion	Ceb'oy	*Allium sp.*	Other vegetables
46	Orange	Chiin	*Citrus sinensis*	Other fruits
47	Pacaya palm	K'ib	*Chameadorea sp.*	Other vegetables
48	Palal			Other fruits

Appendix F continued:

49	Papaya	Papaay	*Carica papaya*	Vit.A rich fruits
50	Passionfruit			Vit.A rich fruits
51	Peach		*Prunus persica*	Other fruits
52	Pear			Other fruits
53	Pig			Flesh meat
54	Pine tree			N/A - Fiber
55	Pineapple	Ch'op	*Ananas comosus*	Other fruits
56	Plum		*Prunus sp.*	Other fruits
57	Quib			Other fruits
58	Radish	Rabano	*Raphanus sativus*	Other vegetables
59	Raxtul	Raxtul	*Pouteria campechiana*	Other fruits
60	Rosemary	Romero	*Rosmarinas officinales*	Spices, condiments, and beverages
61	Santa Catarina	Tzoloj	*Dahlia variabilis*	N/A - Fiber
62	Sheep			Flesh meat
63	St. John's Wart	Pericon	*Tagetes lucida*	Spices, condiments, and beverages
64	Sugar Cane	Utzaaj	*Saccharum officinarum*	Sweets
65	Taro	Ox	*Xanthosoma violaceum*	White roots and tubers
66	Thatch (grass)	Quim ha	*Imperata contracta*	N/A - Fiber
67	Tomato	Pix	*Lycopersicum esculentum*	Other vegetables
68	Tree fern			N/A - Fiber
69	Tree spinach	Roctixl	*Cnidoscolus chayamansa*	Vit. A rich dark green leafy vegetables
70	Turkey			Flesh meat
71	Tz'aaj			Vit. A rich dark green leafy vegetables
72	Tz'uk			Other vegetables
73	Wild animal			Spices, condiments, and beverages
74	Yucca	Tz'in	*Manihot esculenta*	White roots and tubers